TITLE MOVEMENT INTERFERENCE IN VISUO - SPATIAL WORKING MEMORY

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MOVEMENT INTERFERENCE IN VISUO-SPATIAL WORKING MEMORY

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ABBREVIATIONS

A-L Bridge	_	Action-Language Bridge
ADB	_	Apple Desktop Bus
AL	_	Articulatory Loop
ALI	_	Action, Language & Imagination
Anova	_	Analysis of variance
CE	_	Central executive
cm	_	Centimetre
df	_	Degrees of freedom
ERP	_	Event-related brain potentials
F	_	F ratio
HC	_	HyperCard
LTM	_	Long-term memory
LTS	_	Long-term store
MAD	_	Median of the Absolute Deviations from the mean.
mm	_	Millimetre
N	_	Number of subjects
P	_	Probability
PB	_	Picture Brooks
POC	_	Performance Operating Characteristic
QMI	_	Questionnaire upon Mental Imagery
r	_	Pearson correlation coefficient
rho	_	Spearman correlation coefficient
SAS	_	Supervisory attentional system
SB	_	Standard Brooks
SD	_	Standard Deviation
SP	_	Serial position
STM	_	Short-term memory
STS	_	Short-term store

t	_	t test score
TBR	_	To-be-remembered
VMIQ	_	Vividness of Movement Imagery Questionnaire
vs	_	Versus
VSSP	_	Visuo-Spatial ScratchPad or Sketchpad
VVIQ	_	Vividness of Visual Imagery Questionnaire
WM	_	Working Memory

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Finally, it must be pointed out that much of this work is the result of the author's efforts and he solely bears responsibility for any errors it may contain.

DECLARATION

The material presented in this thesis is entirely the work of the author and is not the outcome of work done in collaboration.

I have not submitted this dissertation or any part of it for any other degree or diploma or other qualification at any other university.

SUMMARY

This thesis sets out to examine movement interference in visuo-spatial working memory within the framework of the Baddeley & Hitch model of Working Memory (WM). Many studies have shown that concurrent movement interferes with visuo-spatial processing with interference being mainly marked during active encoding rather during image maintenance. However, it is not clear whether concurrent movement interferes because both tasks share a common visuo-spatial resource or whether interference is due to the involvement of the hypothetical Central Executive (CE).

This study approached this issue via the most widely used task, the Brooks Matrix. After reviewing the evidence which led to the abandonment of the notion of a unitary system and to the proposal of a multi-component model of WM, evidence was then reviewed for the existence of a specialised subsystem, the Visuo-Spatial ScratchPad (VSSP), dealing with the temporary processing of visuo-spatial information and images and that is linked to the planning and control of movement. After reviewing the literature on the VSSP and presenting evidence for the difficulty of the Brooks Matrix task, the thesis moves on to systematically examine the cognitive processes involved in performance of this task. A process-model is then proposed which combines features of both the WM model and Annett's Action, Language & Imagination model. The CE is assigned specific roles in image generation and verbal encoding of the task. Subsequent experiments, using movement interference paradigms, examined the interference effects of various movement tasks on the Brooks Matrix task or on new simplified variants that were assumed to minimise CE involvement. Movement interference was examined during both the encoding and the maintenance stages. Two broad issues were explored, the relationship between the VSSP and the CE, and the nature of the refresh mechanism in the VSSP.

The overall results point to the importance of the CE in visuo-spatial processing and support previous indications that the CE is 'coupled' to the VSSP during active processing. Further, the results appear to indirectly lend support to the notion that the VSSP may indeed comprise two separable spatial and visual subsystems. Finally, the results did not support the proposal of a 'motoric' refresh mechanism in the VSSP that is analogous to the refresh mechanism in verbal WM. Whether subjective reports of imagery vividness correlate with performance on the Brooks visuo-spatial task was examined by the use of the VMIQ and VVIQ questionnaires. Inconsistent results were obtained and a discussion of this issue is provided.

The thesis concludes with a discussion of the implications of the overall results to the structure of WM and suggests that further research into movement interference in visuo-spatial WM is needed until a full understanding of the link between spatial representation and motor control is reached. Tasks developed here including new variants on the Brooks Matrix task and some secondary tasks may be used in future research. Finally, the thesis concludes with pointing out the importance of understanding how movements and actions are represented in WM to the acquisition of motor skills.

Chapter 1

Short-term memory and Imagery

1.1. Introduction and an overview:

The ability to retain information over a short period of time appears to be crucial for a wide range of everyday tasks and skills. In order to know what we are going to do next, it is important to remember what we have just done. For instance, in reading we have to remember what we have just read if we are to make sense of what we are now reading. We also have to retain an unfamiliar telephone number just long enough to dial it. Similarly, when counting we have to remember how far we have gone through the counting sequence in order to know which number comes next (Della Sala & Logie, 1993). In addition, the representation of the spatial and visual characteristics of objects in the environment is central to everyday functioning. The visual form of objects and the relative location of objects can be mentally represented. This enables reaching out and manipulating some of these objects or simply imagining oneself mentally manipulating them. The cognitive abilities and systems that allow us to perform these tasks are different in both their nature and role from memory functions that store general knowledge of the world or information regarding past experiences and life events (Logie, 1995).

The things that we can and can not do with our memories under a variety of conditions could provide us with clues regarding how our memories are organised and structured. Studies on learning lists of items suggested that we have a memory system in which a short-term store (STS) acts as a holding device, a buffer store, until our long-term store (LTS) of well established memories can be accessed in some way for the new material to be encoded and stored. When the material can not be encoded into the LTS quickly enough, information is lost from the STS. If routes to our LTS are impaired, we can repeat digits held in the STS but can not learn them (Smyth, Collins, Morris & Levy, 1994).

Over the past few decades there has been a considerable effort aimed at understanding how human temporary storage of information is achieved. During the 1950s the prevailing view was that memory was a single system with no distinction between a LTS and STS. It was assumed that retaining, for instance, an unfamiliar telephone number and recalling a lengthy sequence of prose learned at school, involved the same system. Furthermore, during that period, the prevailing experimental techniques involved verbal material rather than aspects of other everyday cognitive tasks although there has always been some research on memory for objects, events and motor performance (for a review see Annett, 1985, 1991b; Smyth & Wing, 1984).

The first part of this chapter will provide a very brief historical perspective of the distinction between short-term memory (STM) and long-term memory (LTM). Evidence for such a distinction will be very briefly considered. Some of the major models of this approach such as those of Atkinson & Shiffrin (1968) and Craik & Lockhart (1972), and the problems they encountered, will then be briefly presented. After briefly considering the argument for the existence of a STM store, the argument for the existence of a visuo-spatial STM (and imagery) system will then be considered in the second part of the chapter. This argument was put forward in the suggestion by Baddeley & Hitch (1974, Baddeley, 1986) that STM is better thought of as a working memory system comprising several, substantially independent components. Baddeley & Hitch suggested that working memory (WM) comprises at least three components which are, a supervisory attentional central executive (CE) aided by two slave systems: a verbal subsystem known as the articulatory loop (AL), and a visuo-spatial scratchpad or Sketchpad (VSSP). The VSSP, which is the main topic of this thesis, was assumed to be responsible for temporary processing and retention of visual and/or spatial information and the formation and manipulation of visuo-spatial images. The VSSP is also assumed to be involved in the planning and control of movement.

Following the discussion of the WM model, two additional models will be discussed. These two models are the Dual Coding model presented by Paivio (1971, 1986) and the Action, Language and Imagination (ALI) model presented by Annett (1982). These two models, like the WM model, propose two independent STM systems, one for dealing with verbal material and the other for dealing with nonverbal material. The nonverbal system, like the VSSP, is implicated in the processing of visuo-spatial information and in the setting-up and manipulation of visuo-spatial images. The nonverbal system is often referred to by Paivio as the imagery system since one of its assumed functions is the generation and manipulation of visual images.

The second chapter will then be devoted to reviewing the literature on the VSSP and some controversies and debates within the VSSP domain will be addressed in detail. One of these debates relates to the role of movement in the VSSP, examining which is the main aim of this thesis. This will be followed by stating the research problem and describing the main experimental task. The subsequent four chapters will then describe a series of experiments which systematically attempted to tackle the research question. The thesis will then conclude with a final chapter that provides a summary and discussion of the main results and conclusions.

1.2. Background and historical perspective:

The notion that memory might not be a single monolithic system but might have two or more components was recognised centuries ago. John Locke (1690) made a distinction between contemplation and memory in his description of the 'faculty of retention'. William James (1890) made a similar distinction between primary memory and secondary memory. In the mid 1960s Waugh & Norman (1965) revived ideas similar to those of Locke and James by suggesting two memory systems, a primary memory responsible for short-term storage and a secondary memory responsible for longer term storage. Information in primary memory was assumed to be displaced by new input unless it was maintained by rehearsal, and information could also be copied from primary memory to secondary memory by rehearsal. In the 1960s various sources of evidence were collected for a separation between a STM store and a LTM store. The following is a very brief description of the major sources of evidence (see e.g. Baddeley, 1986, 1990 for details):

1) Recency effect and STM:

One of the major sources of evidence for a distinction between primary and secondary memory comes from the free-recall paradigm in which subjects are presented with a list of unrelated words and attempt to recall them in any order they wish. It has been shown (e.g. Glanzer & Cunitz, 1966) that when recall is immediate, there is a tendency for the last few items to be very well recalled (recency effect), recall of the first few items is reasonably good (primacy effect) whilst items in the middle are very poorly recalled. However, if recall is after a filled short delay, the recency effect disappears whilst the primacy effect is retained. This effect of delay on recency, but not on primacy, was interpreted as suggesting that the recency items are held in a STS whilst the primacy items are held and recalled from a LTS.

2) Acoustic and semantic coding:

A second source of evidence for a dichotomy comes from apparent differences in the nature of the memory coding. Studies of coding in immediate and delayed serial recall of letters and words (Conrad, 1964; Baddeley, 1966a&b) showed that with short-term recall, acoustically similar words were less well recalled than acoustically dissimilar words. Recall of semantically similar words, on the other hand, was very little different from recall of semantically dissimilar words. In contrast, after a delay, the effect of acoustic similarity disappeared but an effect of semantic similarity appeared by which semantically similar words were recalled less well than semantically dissimilar words. Acoustic similarity appeared to affect short-term storage and semantic similarity appeared to affect long-term storage. This was taken as suggesting that the STS retains words in terms of their sounds (acoustic coding) whereas the LTS retains words in terms of their meaning (semantic coding).

3) Neuropsychological evidence:

A strong evidence for a separation between STS and LTS comes from several studies of amnesic and other brain-damaged patients in which a double dissociation has been shown between performance on STM and LTM tasks. For instance, studies of Milner (1966, 1970) described a patient (HM) who had a very pronounced amnesia with a grossly defective ability to learn new information. HM showed an unimpaired digit span coupled with an inability to remember what happened yesterday. This patient provided evidence for damage to LTS or to long-term retention of new information whilst having an intact STS. In terms of the serial position (SP) effect, such patients were shown to have gross impairment in recalling the early (primary) items and to have a normal recency effect. The opposite pattern of impairment was shown in studies such as that of Shallice & Warrington (1970) in which a patient (KF) was described as having an impaired digit span (STS) coupled with normal long-term retention. In terms of the SP effect, such patients were also shown to have the opposite pattern. They show an impaired recency effect which was confined to the very last item in the list whilst showing excellent retention of the early or primary items. Recently, Van der Linden, Coyette & Seron (1992) described a similar case of a patient (AM) with a specific STM impairment and no LTM or intellectual deficit.

By the late 1960s, the evidence appeared to be mounting in favour of a dichotomous view of memory. The Waugh & Norman model of primary and secondary memory appeared to provide a useful framework within which to encompass this two-store view of memory but this model had several limitations. For instance, this model dealt only with verbal rehearsal and storage whilst it was becoming clear that there are other means of rehearsal and storage. It has been shown, for example, that the use of visual imagery can bring about better memory performance in comparison to verbal rehearsal (Paivio, 1971). A number of models, that had much in common, were formulated to account for the more general notion of STM. The most influential of which was the model proposed by Atkinson & Shiffrin (1968) and which is sometimes termed the modal model.

1.2.1. The Modal Model:

The Atkinson & Shiffrin (1968, 1971) model proposed three separate types of memory store (see Figure 1.1). The first and briefest kind of storage is one of a number of sensory information stores which register incoming signals, very briefly holding them in a primitive form which is rapidly disrupted by additional signals in the same sensory channel. These sensory systems are associated with specific input modalities such as vision and audition. These sensory buffers feed information into the second component, a limited-capacity and unitary STS. The contents of this STS are partially conscious as in holding a telephone number while we dial. This STS feeds information into and extracts information from the third component, a LTS. This LTS has a much greater capacity than the STS and from this store we retrieve well-established memories and in it we also store well-processed information.

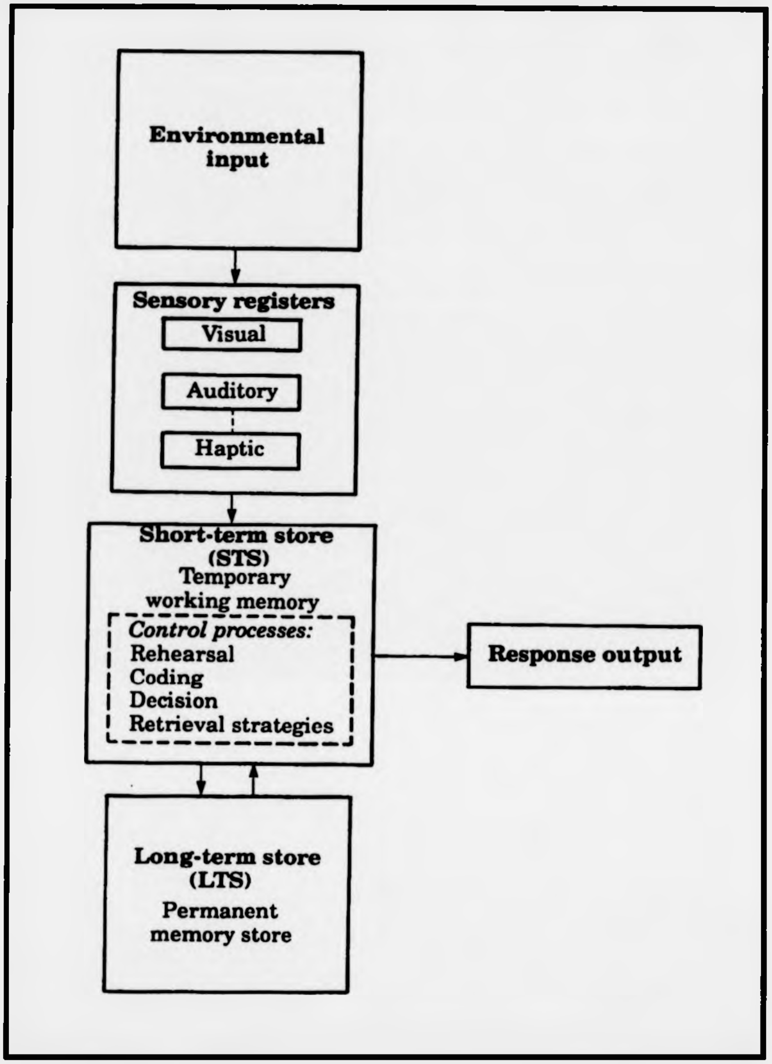


Figure 1.1. The Atkinson & Shiffrin model of memory. (Adapted from Atkinson & Shiffrin, 1968).

The central feature of the model is the STS since without it information can not get into or out of the LTS. Long-term learning depends on holding information in this temporary STS until it is transferred to the LTS. The longer the material is maintained, the greater the probability of transfer to the LTS. The function of the STS was not, however, limited to passively storing information since it was also assumed to be a working buffer performing certain other functions referred to as control processes which are:

-Rehearsal: rehearsal is a process whereby information was maintained in the STS and it requires a transformation of the selected incoming information into a rehearsable form such as a phonemic code for verbal material. Although Atkinson & Shiffrin recognised the existence of semantic coding, their concern was primarily with verbal rote rehearsal. It was postulated that the longer an item is held in the STS, the greater the probability that it will be transferred to the LTS.

-Coding: Maintenance rehearsal might not be enough for some tasks and we need to hold information so that something might be done with it. Further coding of information might be necessary by retrieving some aspects of its previous meaning to us from the LTS.

-Retrieval strategies: The different purposes for processing information such as answering a specific question or performing mental arithmetic are each likely to require different search and retrieval strategies from the LTS.

-Decision making: Such as deciding to shift the direction of a search or deciding that sufficient has been retrieved for an item.

Hence, by the early 1970s, there was reasonable consensus about the need to assume a separate STS. The Atkinson & Shiffrin model appeared to initially solve many of the problems of conceptualising the memory system and to offer a very good account of STM and its relationship to cognition. However, a number of phenomena failed to fit at all well within the framework of the modal model.

1.2.2. Problems with the modal model

The modal model encountered various problems some of which briefly are:

1) <u>STS and long-term learning:</u>

A basic assumption of the modal model was that long-term learning was dependent upon the STS. The probability of an item being learnt increases with its time of maintenance in the STS. A number of researchers such as Tulving (1966) and Craik & Watkins (1973) attempted to test this assumption and found that this was not the case. Maintaining an item in the STS does not necessarily result in long-term learning. The assumption underlying the modal model of probabilistic but automatic transfer from STS to LTS was doubted. Atkinson & Shiffrin appeared to be wrong to suppose that the only route to LTM was via the STS.

2) <u>Neuropsychological evidence:</u>

If the single and limited capacity STS plays a crucial role in general cognition as suggested by Atkinson & Shiffrin, then patients with defective STS should show impaired learning and general impairment in intellectual capacity. Evidence from studies of such patients (e.g. Shallice & Warrington, 1970) showed that this was not the case. Such patients showed no such general impairment and they had normal long-term learning capacity and often lived an independent and normal life. This could only mean that either STM is not the gateway to LTM or that STM comprises several subsystems, not all of which were damaged in these patients.

3) <u>Recency and the STS:</u>

The modal model proposed that the recency effect in free recall and memory span are manifestations of the same limited capacity STS. However, difficulties with this assumption come from various directions. For instance, it has been demonstrated (e.g. Tzeng, 1973) that recency effects could be relatively long-term and resistant to disruption by tasks that could normally be expected to displace items from the STS. The modal model seems to offer only a partial explanation of recency which is one of the phenomena that it was particularly designed to explain. In addition, Baddeley & Hitch (1977) showed that the recency effect was preserved despite carrying out a concurrent digit span task. Such a result is not easily explained by the modal model since both span and recency should have competed for the same unitary and limited capacity STS and thus a massive interference should have been observed.

4) Coding:

The assumption that the STS operates entirely on phonological coding whereas the LTS on semantic coding was shown to be an over-simplification. For instance, in regard to LTM, there is a need to assume a wide range of coding dimensions including phonological coding since without it one could never learn to speak (Baddeley, 1986). However, it remained possible to argue for an absence of semantic coding in STS (Baddeley, 1972) but not to predict in detail where and when a specific type of encoding would occur.

1.2.3. Levels of processing

Problems with the modal model were accumulating and the model did not fully develop the notion of control processes. It was unclear why some processes lead to better long-term retention than do others. One attempt to formalise this relationship was provided by Craik & Lockhart (1972) in their levels of processing model. In contrast to the modal model, Craik & Lockhart emphasised the nature of processing rather than memory structures. Although the modal model had some functional aspects such as control processes and encoding structures, these aspects were, however, subsidiary to the underlying structural distinctions. Craik & Lockhart suggested that memory traces are formed as a by-product of perceptual and attentional processes. Trace durability is a direct consequence of the processes of encoding, with deeper and more elaborate encoding leading to more durable memory traces. Craik & Lockhart proposed that evidence accumulating in the study of long- and short-term memory could be fitted into a simple framework. This assumes that learning material involves processing it through a succession of ever deeper stages, starting with shallow sensory stimulus and ending with deep semantic integration of the material into the subject's existing knowledge. The deeper the processing, the better the learning and recall. Hence, shallow levels of processing were associated with physical features of stimuli whereas deep levels of processing were associated with semantic features such as meaning or associations. The nature of the processing was regarded as more important than an intention to learn.

Levels of processing was greeted by researchers who held a belief in a unitary memory system such as Postman (1975) despite the fact that Craik & Lockhart retained a distinction between primary and secondary memory by suggesting that subjects could maintain information at a given level of processing by a flexible primary memory system that could deal with various codes as required by a given level. However, Craik & Lockhart did not elaborate on the operation of STM within their model, as their model referred largely to the operation of LTM and the association between processing and subsequent retention in LTM.

Levels of processing encountered numerous difficulties during the 1970s, details of which are beyond the scope of this chapter (for details, see Baddeley, 1986, 1990). However, one of the major difficulties was the lack of any definition of depth that did not rely on the subsequently observed level of recall. In other words, there was no sufficient independent measure of depth of processing. Although levels of processing appeared to be an intuitively attractive concept that could account for a good deal of empirical data, it has not proved to be a concept that is easy to develop (Baddeley, 1986) and it seems to provide a less tractable theoretical framework than it initially appeared to offer (Logie, 1995). In addition, although the initial model assumed the existence of a primary memory serving many of the functions required of WM, the way in which the framework has developed has led to the problems of short-term and WM being neglected. Hence, it was considered that the levels of processing framework does not offer a sufficient alternative to a more appropriate model of WM. Such a model of WM was proposed by Baddeley & Hitch (1974) as a second response to the problems of the modal model and this WM model is the subject of the next section of the this chapter.

1.3. The Working Memory Model

1.3.1. Development of the WM model

The WM model grew out of dissatisfaction with the Atkinson & Shiffrin (1968) modal model which conceived of STM as a unitary system reliant upon rehearsal for long-term retention. As mentioned above, the modal model faced numerous difficulties one of which was the observation that certain patients with grossly impaired digit span (STM) can nonetheless learn quite normally. This is inconsistent with the view that a single unitary STM is essential for long-term learning. Such observation also means that either STM is not the gateway to LTM or that STM is not a unitary STS but rather comprises several systems only some of which were damaged in these patients. Another difficulty is related to the assumption that maintaining an item in the STS would ensure its transfer to the LTS which has proven to be poorly supported. Atkinson & Shiffrin emphasised the general importance of the unitary STS and assumed that this single STS acted as a WM system for temporarily holding and manipulating information. Baddeley & Hitch (1974) attempted to investigate the STS and to ask whether it really does serve as a general WM. They did so by challenging the concept of a unitary STS and replacing it by a more complex multi-component WM model.

One important assumption and prediction of the modal model was that since STM comprises a single unitary store, then combining two activities that require the operation of this single system should lead to disruption of the operation of this STS. Baddeley & Hitch attempted to tackle this issue by using a dual-task technique whereby the subject is required to perform one task that absorbs most of the capacity of their STM while at the same time performing each of a range of tasks such as learning, reasoning, and comprehending which are also assumed to crucially rely on STM. If the single STM system assumption is correct, then performing the concurrent task should lead to a significant impairment in performance.

Baddeley & Hitch selected digit span as their concurrent memory task which is supposed to occupy the STS. They required their subjects to remember sequences of digits at the same time as they were performing each of a range of tasks that were also assumed to depend on WM for their performance. In one study, subjects were required to retain a sequence of digits and at the same time carry out a reasoning task devised by Baddeley (1968). This involved verifying a series of sentences that describe the order of a pair of successive letters. Pairs of letters were presented and the task was to decide whether or not the sentence was an accurate description of the letters. For example:
"A follows B - AB" is false, whereas "B doesn't follow A - BA" is true, and so forth.

The assumption was that if the STS was a single limited-capacity system that is used in reasoning, then loading this store with a concurrent task of remembering digits should impair performance. The larger the number of digits held, the greater the amount of WM capacity being absorbed, and the greater the interference with the reasoning task. This is in fact the prediction from the modal model, the digit span task should depend on the single phonetically-based STS, with 3 digits using up a large amount of it whilst 6 digits, being near span, virtually wiping it out and hence interfering with the concurrent task. The obtained results were quite different from this prediction. Retaining a sequence of 3 digits was not interfered with by the reasoning task, and in turn the reasoning task was unaffected by the concurrent digit load. With a load of 6 digits, there was a small increase in the time taken to carry out the reasoning task but there was no effect on accuracy. A broadly similar pattern of results was obtained by Baddeley & Hitch across a range of other cognitive tasks. Baddeley & Hitch indicated that it is not easy to account for this pattern of results if one assumes that WM comprises a single unitary store whose limited capacity is likely to be totally absorbed when the limits of memory span is reached. The concurrent load of 6 digits should have caused reasoning performance to breakdown but it did not. These results were taken as indicating that there are separate cognitive mechanisms involved, one for processing the reasoning task and the other for storing the digits, and that these systems can operate concurrently with only a small amount of dual-task overhead.

From these results and other results, details of which are beyond the scope of this chapter, Baddeley & Hitch concluded that the assumption of a unitary STS was unjustified. They suggested that a solution is to abandon this assumption and accept that the limits of digit span may be set by one of a number of STM subsystems, leaving other subsystems relatively unimpaired. Hence, they proposed a tripartite WM system instead of a single WM system.

1.3.2. Working Memory

As indicated above, the WM model grew out of a dissatisfaction with the numerous problems inherent in the conception of a unitary STM system in the modal model. Atkinson & Shiffrin proposed that transient memory traces act as a WM, that is, a store that engages in processing information in real time. It became clear, however, that the plethora of information-processing capabilities of complex organisms, especially humans, could not be accounted for by a simple short-term/LTM dichotomy. Hence, Baddeley & Hitch (1974) proposed a multi-component WM model. The term WM refers to the temporary storage and manipulation of information involved in the performance of a wide range of cognitive tasks. WM (Baddeley & Hitch, 1974) is thought to provide the functions necessary for tasks that involve short-term storage and processing of information. It is assumed to involve moment-to-moment updating and rehearsal of information to prolong storage (Logie, 1989; Logie, Zucco & Baddeley 1990). The function of WM has been referred to (Richardson, 1993) as that of helping people to keep track of recent events in time (the AL) and space (the VSSP).

Baddeley & Hitch proposed that WM comprises three semi-independent components. The first of which is a modality-free supervisory attentional system, the CE, which is thought to be of a limited capacity and is responsible for reasoning, decision making, and coordinating the activities of two other modality-specific slave systems. The first subsystem, originally called the AL, was thought to be responsible for temporary processing and retention of verbal or speech-based information. The AL is being recently referred to as the phonological loop and the two terms are being interchangeably used here. The AL is assumed (Logie & Baddeley, 1990) to be involved in the translation of visually presented verbal material into a speech-based code. Baddeley & Logie (1992) proposed that the AL may represent the seat of auditory imagery and that there is evidence for its involvement in the temporary storage of auditory images.

The second subsystem, called the VSSP, was thought to be responsible for temporary processing and retention of visual and/or spatial information. The VSSP is assumed to be responsible for setting-up and manipulating visual images (e.g. Baddeley, 1986, Logie, 1989, 1991). It is also assumed (Logie & Baddeley, 1990) to have some involvement in processing visually presented material. Figure 1.2 shows a simple representation of the WM model.

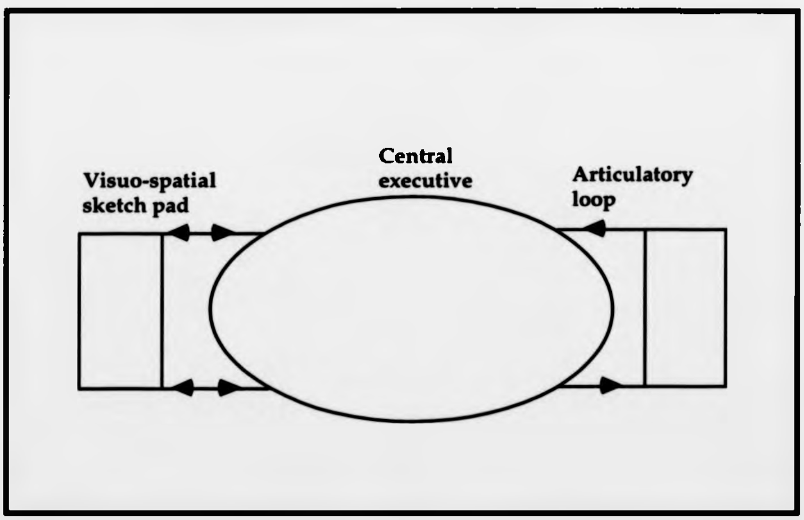


Figure 1.2. A simple representation of the working memory model. (Adapted from Baddeley, 1986)

A succinct summary of the relationship between these three components has been provided by Baddeley (1981). "The CE which formed the control centre of the system was assumed to select and operate various control processes. It was assumed to have a limited amount of processing capacity, some of which could be devoted to the short-term storage of information. It was able to offload some of the storage demands onto subsidiary slave systems of which two were initially specified, namely the AL, which was able to maintain verbal material by subvocal rehearsal, and the VSSP, which performed a similar function through the visualisation of spatial material" (p.18).

The CE is depicted as having two components: an attentional mechanism and a general work space. The general work space is usually used in conjunction with one or more slave systems. The function of the attentional mechanism is to allocate resources. The AL is considered to be more complex than just an articulatory loop and is thought to involve memory for phonology (what words sound like) in addition to articulation (how words are said). The VSSP has also been conceived to be analogous in structure to the AL. These issues will be discussed when considering each of these three components in the next sections.

It has been indicated (e.g. Della Sala & Logie, 1993) that although Baddeley & Hitch (1974) proposed only two slave systems, they admitted that additional specialised subsystems might exist such as tactile, kinaesthetic or olfactory. Reisberg, Rappaport & O'Shaughnessy (1984) attempted to examine such possibility, but a recent study by Ellis (1991) has shown that these alternative codes are very poor predictors of memory performance in comparison to the effect of the verbal and visual codes.

The next section of this chapter will provide a brief description of each of these three WM components. The third component, the VSSP, which is the main topic of this thesis will be discussed in detail in chapter 2. Chapter 2 will be fully devoted to examining the proposal that one function of STM is to store and manipulate visuo-spatial information and images. Various debates and controversies in the visuo-spatial WM domain will be considered in detail, particularly those pertaining to the role of movement in the VSSP.

1.3.3. The Central Executive

The CE is considered to be the most complex component of WM. It is thought to act as a general attentional resource and to be involved in decision making, reasoning, comprehension, calculation and long-term retention in addition to coordinating the operations of the two subsystems. The CE is also the core of WM that regulates the flow of information, the retrieval of information from LTM, and the general purpose storage and processing which allow operations to be applied to information held in memory. Baddeley (1992b) indicated that the CE is the most important but least well understood component of WM. It was initially neglected on the grounds that the peripheral subsystems offered more tractable problems, but has subsequently began to attract more research. Naveh-Benjamin (1993) indicated that this is to be expected considering that the subsystems are more modular in nature and more peripheral, that is being closer to the input or the output stages. Unlike the CE, the greater accessibility of these subsystems facilitated progress in developing methods and paradigms to investigate them.

Baddeley (1986) pointed out that the CE has served, in addition to its supervisory role, as a conceptual ragbag within the WM literature, that is any process which was considered as part of WM but outside the specific system being studied, has tended to be referred to as operating within the CE. In fact, the CE has been described (Baddeley, 1981, 1986) as the area of residual ignorance within the WM system. Morris (1986a) indicated that there is also considerable amount of residual ignorance associated with the other components. It is this residual ignorance which requires postulating a general processor, as yet we do not have the necessary techniques to fractionate the system further. Baddeley (1981) predicted that further components of the central processor will be fractionated since it has been observed that heavy memory loads assumed to load the general store have rather small effects on other cognitive processes. Halliday & Hitch (1988) indicated that the CE is the least well understood component and that the related concept of a limited-capacity central processor has been criticised on a number of grounds (e.g., Allport 1980). It has even been suggested (Barnard, 1985) that the subsystems of WM may be able to co-operate without the need for a CE at all, although it is not clear how this might be achieved. Most researchers have devoted their work to the more tractable study of the subsystems in the hope that by delimiting their functions, that of the CE will become clearer.

The model for the CE is not developed within the WM framework but is derived from other research. Baddeley (1986, 1990, 1992a) argued that since many of the CE functions are basically attentional, it is possible to gain some understanding of the CE from theories of attention. In fact, Baddeley (1993) has indicated that the CE is primarily concerned with attention and coordination rather than with storage. However, Baddeley pointed out that much of the work on attention offered little help in attempting to formulate the functioning of the CE since this work has been concerned with perceptual selection (e.g. Broadbent, 1958, Posner, 1980) whereas the CE is basically concerned with the integration of information and the attentional control of action. One model, Baddeley argued, was however concerned with exactly this problem and has proved to offer a good candidate for a preliminary model of the CE. This model was proposed by Norman & Shallice (1986) to provide a general account of the control of action.

The Norman & Shallice SAS model

Norman & Shallice (1986) were interested in the issue of how activities are controlled and why this control sometimes breaks down. They accepted the assumption that a variety of processes are used in action and thought-processes, and suggested that the control of their on-line operation involved two qualitatively different types of mechanism. A representation of their model is shown in Figure 1.3.

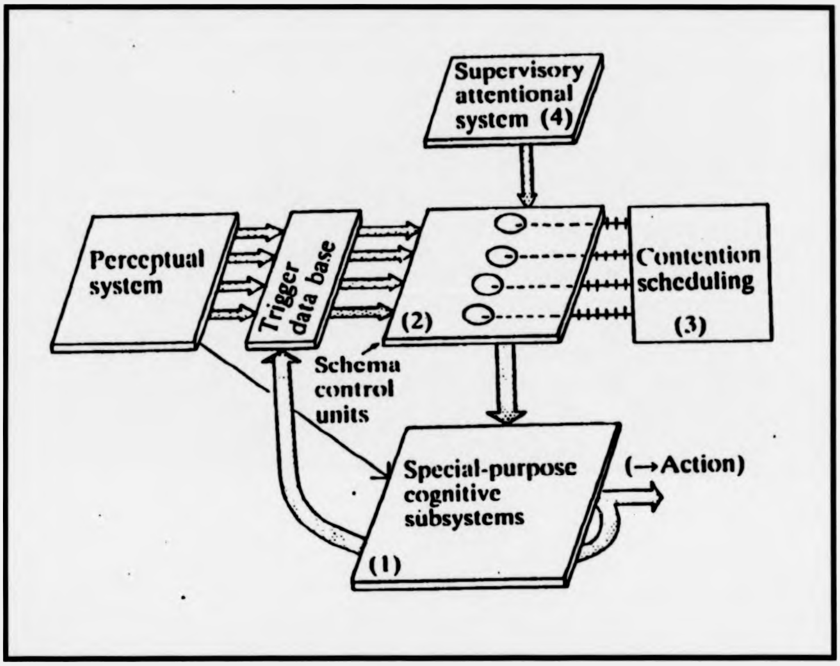


Figure 1.3. A simplified version of the Norman & Shallice (1986) model representing the flow of control information. (Adapted from Shallice, Burgess, Schon & Baxter, 1989).

The first or lowest level of controlling action involves the operation of a series of existing action or thought schemata. Routine actions, such as walking, drinking and talking, are controlled by existing schemata which are collections of actions or motor programs that are run off automatically given the appropriate triggering, and with relatively little demand for supervisory control. Schemata are (Shallice & Burgess, 1993) program-like entities, one for each qualitatively distinct basic well-learned type of action or thought. When two ongoing activities come into conflict and it becomes necessary to give priority for one over the other, then decisions at this level can be carried out by a relatively automatic process known as

"Contention Scheduling" whereby simple rules are built into the system and can be operated automatically. Coordination between different routine actions is also achieved by these contention scheduling procedures which, for instance, allow us to talk and walk at the same time. Hence, the selection of which schema or schemas is or are to be operative at one time was achieved by the contention-scheduling mechanism which resolved conflicts through lateral inhibition between independently activated schemas (Shallice & Burgess, 1993).

The second component of the Norman & Shallice model is called the supervisory attentional system (SAS) which they liken to the operation of the will. Baddeley (1990) indicates that without this component, the model leaves the actor captive to habitual programs, interacting with whatever is encountered in the environment. The SAS was thought to be involved when coping with novelty or performing novel tasks, and it modulates the operation of contention scheduling by providing additional activation or inhibition of schemas competing in the lower-level component. The SAS involves conscious control and is called for when a situation arises in which the next stage is not obvious, or when a new high-priority stimulus occurs which needs to override the ongoing behaviour. The SAS was considered to be of limited-capacity and is called for under five types of situations that involve: **1)** planning or decision making; **2)** error-correction or trouble-shooting; **3)** responses that are not well-learned or contain novel sequences of action; **4)** danger or are technically difficult; **5)** the overcoming of a strong habitual response or the resisting of temptation (e.g. the stroop test).

The Norman & Shallice model has been shown to be capable of accounting for a diverse array of data including the attentional lapses and slips of action, as well as giving an account of the diverse symptoms shown by patients with frontal-lobe damage. For instance, regarding slips of action, a person, being preoccupied with something, enters his garage to pick up the car to go shopping, and suddenly he finds that he has put on his gardening boots. This is explained (Baddeley, 1990) by assuming that the SAS, having set up the going to shop program, was preoccupied with something else and hence leaving the program to run on. Sight of the boots acted as a trigger for the chain of responses associated with the gardening routine and that this was able to override the original intention of getting into the car to go shopping. Patients suffering from the frontal lobe syndrome (e.g. Shallice & Burgess, 1993) are particularly prone to this tendency, sometimes showing a phenomenon known as 'utilisation behaviour' whereby any object incidentally encountered will be picked up and used, regardless of how appropriate the utilisation at that time.

Shallice (1982, 1988) suggested that the SAS depends on the functioning of the frontal lobes, and argued that the frontal lobes play a crucial role in planning and organising action. Patients suffering from the frontal lobe syndrome were assumed to have a deficit to the SAS. Recently, Shallice & Burgess (1993) described various studies involving patients with frontal lobes damage, and concluded that it would seem to be inappropriate to consider the SAS as a single resource, and argued that making the assumption that the SAS exists and can fractionate is proving to be a fruitful assumption.

The SAS as a Central Executive

Baddeley (1986, 1990, 1992a&b, 1993) has equated the SAS with the CE system of WM. Adopting the SAS as the core of the CE appears to be a logical approach that provides a conceptual framework within which to explore the relationship between WM and automated action (Logie, 1993). However, Della Sala & Logie (1993) indicated that a problem with an approach based on the "Attention to Action" model is that it does not clarify the relationship between the CE and the subsystems of WM, and provides only a modest insight into the characteristics of the CE itself (as monitor and organiser of learned procedures).

Baddeley pointed out that the SAS model seems to be able to account for a wide range of WM data and in particular impairments and observations on patients with frontal lobe deficits and Alzheimer's disease. It has also been useful in interpreting the performance of normal subjects in tasks that are thought to involve the CE such as random generation and card sorting. For instance, in regard to random generation, Baddeley indicated that adopting the SAS provided an explanation for puzzling data on the capacity for random generation.

In this task (Baddeley, 1966c), subjects are required to generate and say letters from the alphabet at random. After about 15 to 20 letters, subjects report an increased difficulty with the same few letters tending to crop up, and with a tendency for sequences to follow familiar acronyms such as BBC, or stereotyped patterns such as DEFG. Deviation from randomness is measured in terms of the frequency of individual letters or pairs of letters, or in terms of the number of alphabetic stereotypes that are produced. If the rate of generation is varied then a very lawful pattern emerges with the randomness increasing with the logarithm of the time available. A rapid rate leads to deviation from randomness with redundancy and stereotype increasing linearly with the logarithm of the rate of generation. Also, when the number of alternatives is systematically varied, the rate of generation decreases with set size up to about eight, at which point it levels off. This suggests that subjects can cope with up to 8 alternatives simultaneously, with smaller numbers allowing more attention and faster selection. Once the system's capacity is reached (7 items), adding further alternatives will not affect performance.

Baddeley indicated that although this pattern of results was very lawful, it was not clear how to theoretically account for it. It does, however, fit into the Norman & Shallice model as follows: the task of producing streams of letters is a task for which there is already existing strong schema or internal program which is reciting the alphabet. But to do so will break the rule of keeping the sequence as random as possible. The only way to avoid breaking this rule is for the SAS to continuously intervene so as to select new strategies and ensure output randomness. If the SAS is of a limited capacity, then the faster the rate of generation the less capable will it be in monitoring outcome and switching strategies. Baddeley (1992a) indicated that in addition to illustrating the usefulness of the SAS model, random generation offers a potential tool for loading the CE as a secondary task.

Functions of the CE:

Within the WM model (Baddeley, 1986) the CE is assigned certain cognitive functions that require moment to moment monitoring and are not handled by the specialised subsystems such as decision making, problem solving, calculating, reasoning, and comprehension. The CE is also assigned the function of coordinating the activities of the subsystems since it is unlikely that the coordination could be provided by the subsystems themselves although some authors have argued otherwise (e.g. Barnard, 1985). The CE is further assigned the function of coordinating the flow of information between the subsystems and LTM. The following is a brief description of some of these functions (for details, see Baddeley, 1986, 1990; Logie, 1993; Della Sala & Logie, 1993).

1) Learning and retrieval:

The CE is assumed to be responsible for communication with LTM and other elements of the cognitive system (Halliday & Hitch, 1988). People can learn new information and can retrieve information that has been learned. Baddeley, Lewis, Eldridge & Thomson (1984) examined the effect of loading WM with a concurrent CE secondary task, on learning and retrieval and concluded that the CE is important for long-term learning. Della Sala, Laiacona, Spinnler & Trivelli (1992) have shown that autobiographical retrieval relies on intact functioning of the CE.

2) Language comprehension:

The CE is also assumed to play a crucial role in comprehension. Logie (1993) argued that the role of the WM subsystems appears to be ancillary to the main task of comprehension, and that comprehension appears to depend more on the CE. Baddeley (1990) after discussing some studies in this area (e.g. Oakhill, Yuill & Parkin, 1986) concluded that the crucial feature that distinguishes good from poor comprehenders is not the AL but is the functioning of the CE.

3) Reasoning, problem solving, and planning:

The CE has been indicated to be involved in logical reasoning tasks (e.g. Baddeley & Hitch, 1974; Baddeley, 1986). Recently, Gilhooly, Logie, Wetherick & Wynn (1993) concluded from two studies that the CE played a major role in performance of syllogistic reasoning tasks whereas the AL had a lesser role and the VSSP was not involved. In addition, the use of the CE has been indicated (Logie, 1993) as being essential in mental arithmetic in addition to the AL.

4) Memory updating:

One of the functions suggested for the CE is that of updating information in memory. Morris & Jones (1990) used a dynamic memory updating task, running memory, in which subjects were presented with lists of consonants, one at a time and asked to keep remembering the last four consonants at any point so that they could recall them if they were asked to. Thus, subjects had to keep updating the four consonants they were holding for output, by dropping the oldest item and adding the most recent one. It was found that updating of WM in real time is coordinated by the CE. Recently, Van der Linden, Bredart & Beerten (1994) investigated age-related differences in updating WM using a running memory task. Their results showed that the more numerous the required updating operations, the more the older subjects' performance dropped. Hence, it was concluded that elderly subjects have decreased CE resources, with the processing functions of the CE, rather than its storage capacity, being particularly affected by this deficit.

5) Dual task coordination:

A basic function of the CE is that of coordinating the activities of the subsystems and coordinating information from different sources (Baddeley, 1986, 1992a,b&c; Logie, 1993). A coordinating function implies that the system is involved in allocating attention. Within the literature on attention, there are parallels to the WM model specifically the framework of multiple resources (e.g. Wickens, 1984) which concentrated on two specific resources that are involved in processing verbal and visuo-spatial material. The effect of dual-task performance has been referred to in the attention literature as "cost of concurrence" (e.g. Navon & Gopher, 1979). The coordinating function has also been referred to as an 'executive time-sharer' (e.g. Hunt & Lansman, 1981; Mcleod, 1977), a concept that closely resembles the coordinating function of the CE.

Support for this coordination function has been gathered from studies on patients with Alzheimer's disease. Normal adults are assumed to be able to perform two tasks concurrently with little overall cost, provided the tasks rely on separate cognitive systems (e.g. Baddeley & Hitch, 1974; Farmer, Berman & Fletcher, 1986). Alzheimer's disease has been indicated to be associated with a marked deficit in the functioning of the CE rather than the subsystems (e.g. Spinnler, Della Sala, Bandera & Baddeley, 1988). Thus, if the CE is responsible for coordinating information from separate subsystems, then a CE impairment should lead to an inability to coordinate two different tasks performed simultaneously.

Some studies have attempted to test this issue. For instance, Baddeley, Logie, Bressi, Della Sala & Spinnler (1986) showed that normal elderly subjects and Alzheimer's patients could normally perform a verbal or a visuo-spatial task when these were performed singly. However, Alzheimer's patients showed a significant deterioration in performance when they had to perform the two tasks concurrently whereas normal subjects showed no such impairment. In a subsequent longitudinal study, Baddeley, Bressi, Della Sala, Logie & Spinnler (1991) showed that, as the disease progressed, performance on the combined tasks, but not on the individual tasks, deteriorated markedly, as would be predicted by the hypothesis of a CE deficit in Alzheimer's disease. It was concluded that these patients had an impairment in the coordinating function of the CE. A recent study by Dalrymple-Alford, Kalders, Jones & Watson (1994) examined whether Parkinson's disease patients have deficits in the coordination and integration function of the CE. Using a paradigm similar to that of Baddeley et al, they found that Parkinson's disease patients were less able, than matched controls, to coordinate two concurrent tasks, suggesting that these patients have an inefficient CE.

1.3.4. The Articulatory Loop

The first subsystem of WM is specialised in temporary storage and manipulation of verbal material and was originally called the AL, by analogy with a loop of audio-recording tape. It was thought to be a self-contained system which could keep on repeating a sequence without needing any central control (Smyth et al, 1994). Baddeley (1990, 1992c) indicated that this subsystem is the simplest and most extensively researched component of WM partly because it is so close to the earlier concept of STM. In contrast to the CE and indeed the VSSP, the concept of the AL has become significantly more sophisticated (Baddeley & Logie, 1992).

In its current revised model, the AL is being referred to as the phonological loop and is fractionated into two components, a passive phonological store and an articulatory rehearsal process based on inner speech (Baddeley, 1986, 1990, 1992a,b&c, 1993). The phonological store is capable of holding speech-based material for about 1-2 seconds after which the memory trace fades unless refreshed by the articulatory rehearsal process. This rehearsal process serves two functions: it can maintain material within the phonological store by subvocal rehearsal or repetition, and secondly it can transfer visually presented material such as words into the phonological store by converting it into a phonological code and then registering it in the store by subvocalisation. Smith, Reisberg, & Wilson (1992) pointed out that this concept of verbal WM relies on a partnership between the phonological store (the inner ear) and subvocal rehearsal (the inner voice). The inner ear contains material recently heard, or material recently subvocalised by the inner voice. Smith et al proposed a similar partnership for auditory imagery. A simplified representation of the AL model in its current revised form is shown in Figure 1.4.

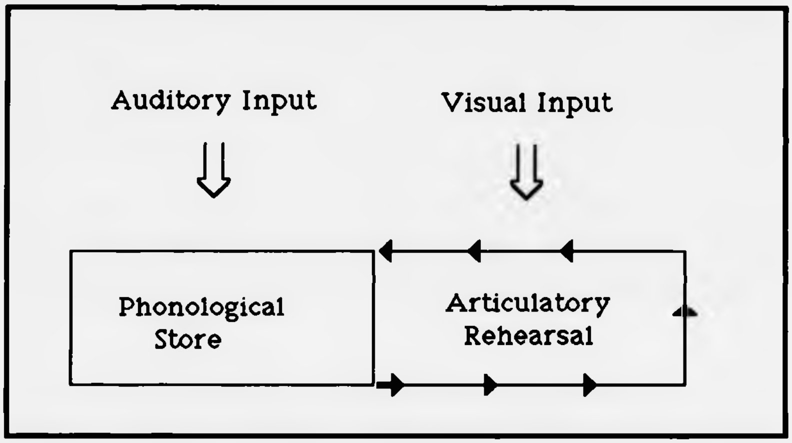


Figure 1.4. A schematic diagram of the phonological (articulatory) loop component of WM (Adapted from Logie, 1993).

This simple model of a phonological store being served or maintained by articulatory rehearsal was, according to Baddeley, able to account for various phenomena some of which briefly are:

1) <u>The phonological similarity effect</u>

This refers to the finding that immediate recall of a series of words or letters is more difficult when they sound alike than when they are dissimilar in sound. This effect is widely replicated and it appears for verbal material whether they are heard or read (e.g. Baddeley, 1966a). This effect is assumed to occur because the basic code involved in the store is phonological and thus similar items will have similar codes and less distinctive features, and subsequently will be more susceptible to being forgotten. Similarity of meaning does not have this effect suggesting that this subsystem does not reflect semantic coding.

2) Irrelevant speech effect

Verbal serial recall is also disrupted by the concurrent presentation of irrelevant spoken material. The semantic characteristics of the material are also not important, with nonsense syllables being as disruptive as meaningful words. This effect has been referred to as the unattended speech effect (Salame & Baddeley, 1982) and is interpreted under the assumption that irrelevant speech gains obligatory access to the phonological store, corrupting the memory trace.

Salame & Baddeley found that irrelevant speech interfered with immediate recall of visually presented verbal items, but that this was not affected further by word length. The more similar the irrelevant speech sounded to what was being remembered, the more it interfered. They argued that irrelevant speech was not articulated because this would have interacted with word length, but that it did get access to a store that is specific for the phonological characteristics of speech. Hence, they divided the AL into two components, a passive phonological store and an articulatory rehearsal process as explained above. These findings are indicated by Baddeley (1990) as having practical implications. For instance, in the studies of noise, most researchers have concentrated on sound intensity as the main variable of study whilst these findings suggest that the qualitative nature of noise may be more important in disrupting WM.

3) Word length effect

In immediate verbal serial recall, sequences of long words can be recalled less effectively than sequences of short words. This effect appears to apply to the length of time it takes to pronounce a word rather than to the number of letters it contains (Baddeley, Thomson & Buchanan, 1975a). This is seen as reflecting the operation of subvocal rehearsal. Long words take longer to rehearse than short words and thus allow greater degree of trace decay of earlier words before the next rehearsal cycle. Memory span for items appear to inversely depend on their speaking rate. This phenomenon has been indicated to account for differences in digit span in different languages. Languages in which digits tend to have long vowel sounds or more than one syllable, take longer to rehearse and lead to shorter memory spans. For instance, digit spans in Welsh, Arabic and Hebrew have been shown (Ellis & Hennelley, 1980; Naveh-Benjamin & Ayres, 1986) to be lower than it is in English. This cross-language difference is indicated (Logie, 1993) as having implications for the design of mental ability tests in different languages. In addition, this word-length effect was used (e.g. Hitch & Halliday, 1983; Halliday & Hitch, 1988) to explain the tendency for digit span in children to increase with age. As children get older, the speed at which words can be rehearsed increases.

4) Articulatory suppression

Retention of a verbal sequence is impaired by requiring subjects to repeatedly articulate some irrelevant word such as "the the the". This occurs because this technique suppresses the use of the subvocal rehearsal process. This articulatory suppression prevents subjects from subvocally rehearsing the to-be remembered (TBR) material. Thus it removes the word-length effect for either auditorly or visually presented material since the word length effect relies on subvocalisation. It also blocks the articulatory rehearsal process, thus preventing subjects from registering visually presented verbal material in the phonological store leading to poorer recall and removal of the phonological similarity effect (Murray, 1968; Baddeley et al, 1984).

In addition to these four phenomena presenting evidence for the AL, further support has come from studies of patients with verbal STM deficits. Some patients have been described who show patterns of impairment of some of the phenomena described above (Baddeley, 1990; Della Sala & Logie, 1993, for details). Such patients have been shown (e.g. Vallar & Baddeley, 1984) to only be able to remember 2 or 3 digits but otherwise have normal verbal and performance IQ, excellent LTM, and normal spans for visual patterns or sequences. They typically do not show phonological similarity effect with visual presentation, nor do they show word length effect with either visual or verbal presentation, or any influence of articulatory suppression. This was seen as reflecting a deficit in the phonological store component of the AL, and hence the AL is not used by these patients in verbal STM tasks. These patients were assumed as not attempting to feed visually presented material into the phonological store because it would simply feed information into a defective store which would do little to enhance performance. With auditory presentation, the information goes directly into this defective store.

Functions of the articulatory loop

The AL is assumed to play a functional role in learning and executing various skills. The following is a very brief description of some of these functions (Baddeley, 1990, 1992a&b; Logie, 1993).

1) Learning to read:

Baddeley (1990) argued that this subsystem plays an important role in learning to read. Children with difficulties in learning to read despite having normal IQ, are indicated to have a common feature which is an impaired verbal memory span. For these children, initial reading is handicapped by some form of phonological deficit. However, these data are considered to be equivocal as evidence for the importance of the AL in learning to read due to various reasons details of which are beyond the scope of this chapter.

2) Language comprehension:

The involvement of verbal STM in language comprehension rests on the assumption that individuals have to store the words long enough for comprehension to take place. There is evidence (e.g. Vallar & Baddeley, 1987) that the phonological input store plays a clear role in comprehension but only for complex or demanding material. Baddeley (1992c) indicated that this store serves as a backup system for comprehension of speech under taxing conditions, but may be less important with simple material. Saffran & Martin (1990) summed up several patterns of comprehension difficulties and their relation to STM by describing the phonological STM representation as the glue that binds together the various representations constructed when we process sentences.

3) Vocabulary acquisition:

Phonological STM has been found to be crucial in vocabulary development, both in children learning their first language and in older children learning a second language. For instance, Gathercole & Baddeley (1990) showed that young children who had good phonological skills were much better at learning nonsense names than their counterparts who had poor phonological skills. Gathercole, Willis, Emslie & Baddeley (1992) found that nonword repetition capacity, which is assumed to depend on short-term phonological storage, was the best predictor of children's vocabulary in their first language. Finally, Baddeley, Papagno & Vallar (1988) showed that a patient (PV), with a specific phonological STM deficit, had a great difficulty in learning foreign language vocabulary relative to matched control subjects. This result was also taken as suggesting that short-term phonological storage is important for new long-term phonological learning.

4) Counting and mental arithmetic:

Accurate counting requires some means of keeping track of a cumulative total and mental arithmetic would similarly require some means of retaining and updating partial totals or products (Logie, 1993). The subvocal rehearsal component of the AL has also been shown to play a role in counting and mental arithmetic in normal adults (Logie & Baddeley, 1987). Evidence from patients with verbal STM deficits also support this finding. However, as indicated by Logie (1993), the AL appears to be rather involved in maintaining accuracy in these tasks whereas much of the processing is accomplished by other parts of the WM system (i.e. the CE as explained earlier in this chapter), with only a partial but important reliance on verbal WM.

1.3.5. The Visuo-Spatial SketchPad

The second subsystem assumed by the WM model is the VSSP which is thought to be responsible for short-term representation of visual and/or spatial information, and the setting-up and manipulation of visuo-spatial images. A full account of this subsystem, which forms the theoretical basis for the to be described empirical work, will be provided in the next chapter. Evidence for the dissociation between the AL and the VSSP will be discussed, followed by a description of the literature on the development of the VSSP. Various issues and debates regarding the characteristics and the structure of the VSSP will then be considered, leading up to the issue of movement interference in visuo-spatial memory and imagery.

However, it is thus far clear that the WM model proposed two separate subsystems, one for temporary processing and manipulation of verbal material, and possibly representing a seat for auditory imagery; and the other for temporary processing and manipulation of visuo-spatial information and images. The remainder of this chapter will provide a description of two other relevant models which also assume the relative independence of the verbal and nonverbal coding systems. These two models are Paivio's dual coding model and Annett's ALI model.

1.4. Dual Coding Theory

Paivio's dual coding theory (Paivio, 1971, 1986) is considered one of the first and still influential theories of imagery and mental representation. In general, mental representation is typically defined as something exhibited to the mind that is symbolic (stands for something) and varies in abstractness (from pictures to linguistic descriptions). Paivio's proposal was that information could be stored either visually or verbally, and that these two codes together could lead to better retention than one code alone.

Paivio based his theory on the view that cognition consists of symbolic representational systems that are specialised for dealing with environmental information in a way that serves functional and adaptive behavioural goals. A view which implies that representational systems must include perceptual, affective, and behavioural knowledge. Human cognition, Paivio argues, is unique since it has become specialised for dealing simultaneously with language and with nonverbal objects and events. The language system is also peculiar in that it has a functional duality, it deals directly with linguistic input and output in the form of speech or writing whilst at the same time serving a symbolic function regarding nonverbal objects, events, and behaviours.

The theory assumes that verbal and nonverbal information are represented and processed in independent, but interconnected, symbolic systems, and that the nature of the symbolic information differs qualitatively in the two systems. The verbal system is more directly accessed by linguistic stimuli and is specialised for sequential processing. The nonverbal system is a parallel processing system specialised for the processing of information concerning nonverbal objects and events. It is often referred to as the imagery system since its critical functions include the analysis of scenes and the generation of mental images. Figure 1.5. summarises the structural assumptions of dual coding.

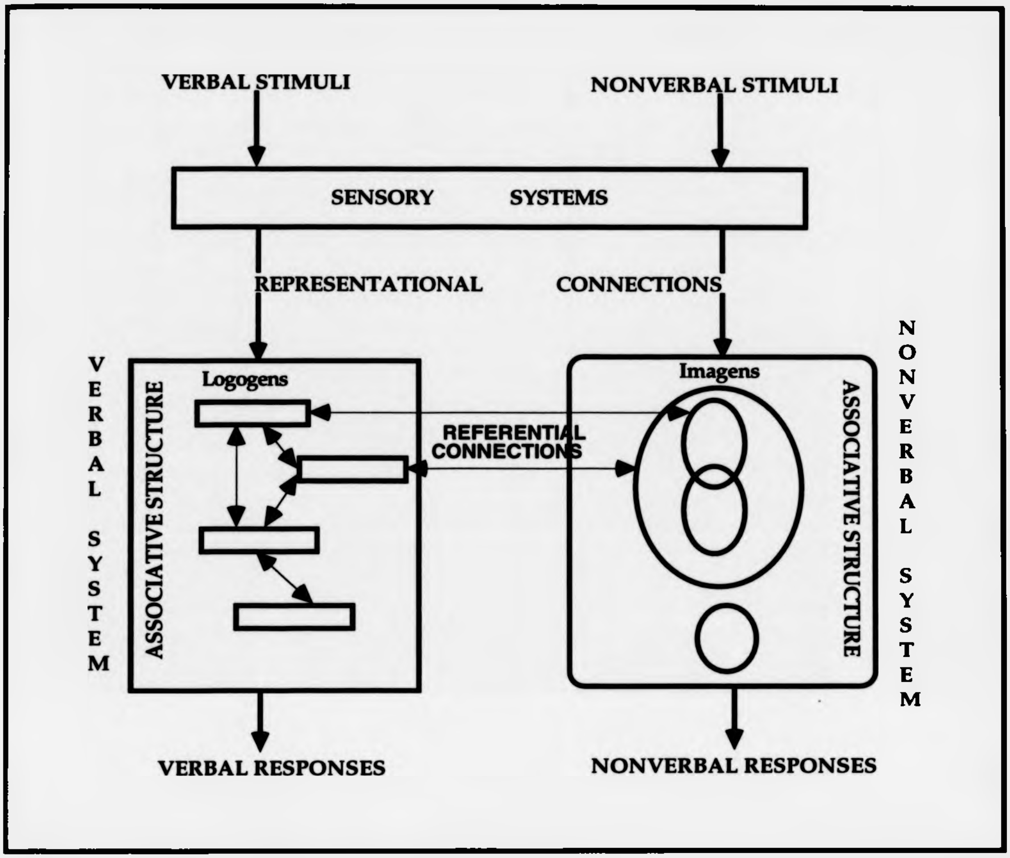


Figure 1.5. A schematic diagram of the structure of verbal and nonverbal symbolic systems. (Adapted from Paivio, 1986).

The two representational systems are assumed to be structurally different in terms of the nature of representational units and the way the units are organised into higher order structures. The structural representations refer to relatively stable LTM information corresponding to perceptually identifiable objects and activities, both verbal and nonverbal. The two systems are also functionally independent in the sense that either system can be active without the other or both can be active in parallel. However, the two systems are also functionally interconnected so that activity in one system can initiate activity in the other by producing referential connections between the two systems as well as associative connections among representations within each system as shown in the Figure. Hence, the preferred metaphor in dual coding is that one system triggers activity in the other, rather than the idea that information flows from one to the other.

This interconnectedness is indicated (Hall, 1980) as capturing the idea that nonverbal information can be transferred into verbal or vice versa; pictures can be named, words can evoke nonverbal images, and similar transformations can occur entirely at the cognitive level. The ability of the verbal and imagery systems to translate input into the opposite system suggests a common code exists between the two systems. Paivio indicated that it is not clear that the referential relations are symmetrical. For instance, people can name focal colours as quickly as familiar objects, but can they image as quickly to colour names as to object names? And when they image colour, do they image colours alone or concrete objects for which the named colour is a typical attribute?

Hence, according to Paivio, the two classes of representation could be engaged by various functional activities including the activation of either by appropriate stimuli (encoding), activation of one by the other (recoding), organisation and elaboration of information within each, as well as transformation, manipulation, and retrieval of information from either class. Each system is also depicted as consisting of subsystems that correspond to different sensory modalities and are capable of functioning independently.

In comparing this model to the WM model, Logie (1995) indicated that the proposal of the WM model of a linkage between WM and imagery could be seen as reminiscent of Paivio's theory. At first sight, the verbal and nonverbal systems could be associated with the AL and the VSSP respectively. In addition, like Paivio's model, the WM model assumes that retention of information may be better when the representation includes material held in the AL and the VSSP. However, unlike Paivio's model which assumes that the generation of an image from a presented word requires access to the word's semantics not its phonology, the WM model assumes that semantic information is rather entertained by the CE not the AL. In addition, Logie argues, it appears from new evidence that image generation is the prerogative of the CE whilst properties of the image are retained by the VSSP. Hence, Logie concluded that the dual coding model bears only a superficial resemblance to the WM model.

1.5. Action, Language & Imagination (ALI) Model.

The overall purpose of this research program is to examine the role of movement in motor STM and imagery. A relevant model to this issue was proposed by Annett (1982) which was designed to account for research into action and motor representation. Annett presented a theoretical framework which was aimed at integrating ideas on the relationship between declarative and procedural knowledge and the process of learning motor skills from demonstrations and verbal instructions, and also providing some insight into the nature of motor imagery.

Briefly, Annett was particularly interested in the relationship between verbal and motor processes. He proposed a model called the ALI model which was intended to provide a theoretical framework for understanding the relationship between verbal and motor or visuo-spatial processes and the role which imagery might play in communication between the two systems. The model (see Figure 1.6) proposes two parallel and independent input-output channels or systems, one specialising in perceiving, remembering, and producing actions, and the other specialising in perceiving, remembering and producing verbal (spoken or written) material.

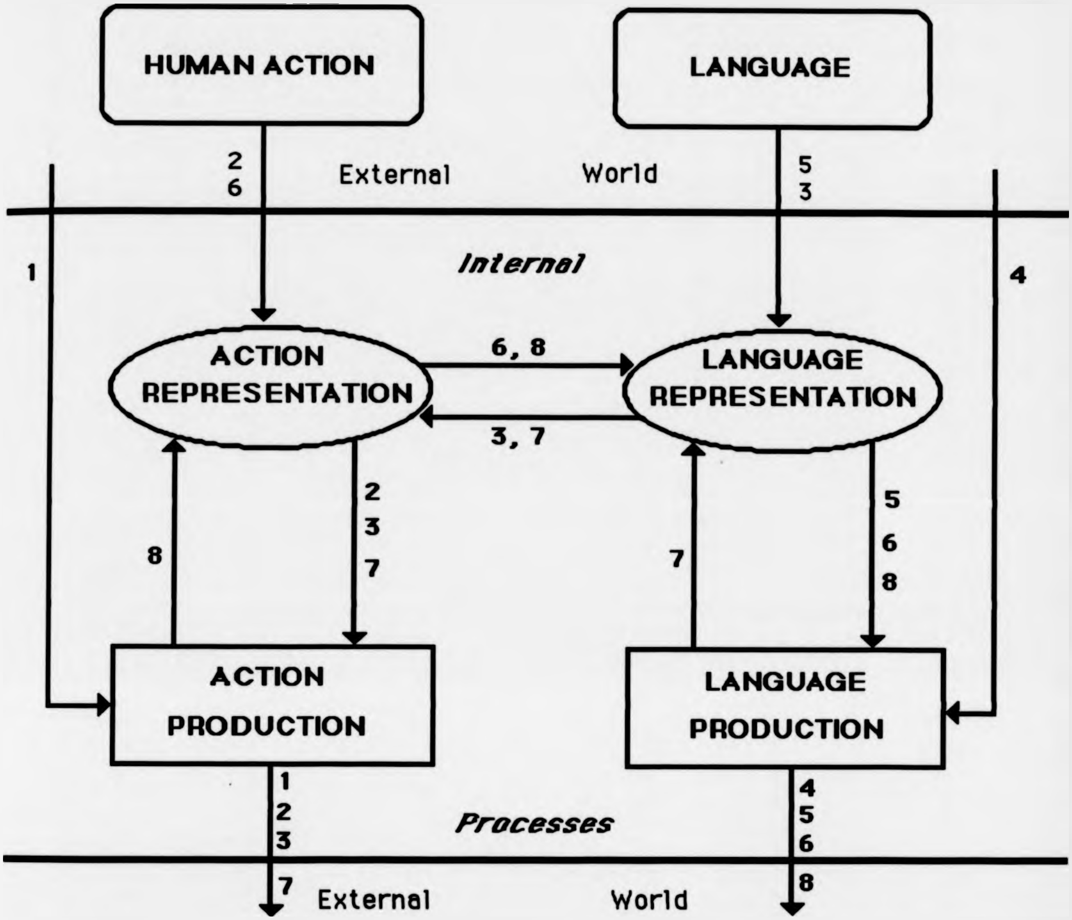


Figure 1.6. The Action, Language & Imagination Model (Adapted from Annett, 1982)

As can be seen in the Figure, each channel comprises two elements, one representational and the other executive or productive. Annett (1990) indicated that each channel comprises a representational component, actions are represented as schemata, or generalised motor programmes, and the language representational system contains semantic and syntactic elements or 'logogens' employed in language production. Within each channel, the representational (sensory) and productive (motoric) elements are represented separately in recognition of the fact that production can be inhibited, although an intimate relationship between them can be assumed (Annett, 1991b). The representational processes are involved in recognising and interpreting incoming data, actions or speech respectively, whereas the production processes are involved in the execution of motor acts or speech, but they can be inhibited when engaged in inner speech or imaginary action.

Hence, Annett proposed a channel specialised in the encoding, recognition, storage and production of action, and this channel comprises a representational subsystem and an executive subsystem. Annett (1994c) argues that the representational subsystem involves conscious processes providing an arena for perceiving or imaging actions (equivalent to the VSSP), and unconscious processes in the form of schematic motor patterns or prototypes held in LTM but entering consciousness when activated. Annett (1990, 1994c) indicates that in action production, there is a close interaction between the representational and executive systems possibly involving shared cerebral mechanisms. When an action prototype is activated, it will provide control signals for the executive system. Both motor empathy and motor imagery would seem to require such a mechanism. However, the representational and executive systems can be decoupled during perception and imagery such that perception is not inevitably translated into imitative action and also allowing for motor imagery. This decoupling is apparent in situations such as passively observing the actions of others. Evidence for this decoupling of representational and executive functions in motor imagery comes from various sources. For instance, it has been shown (Annett & Smith, 1988) that Parkinson's disease patients could perform normally the imagery dependent task of explaining how to tie a bow whilst their actual performance of bow tying was grossly impaired. Such result indicates (Annett, 1990, 1991a, 1994c) that effective action imagery does not involve the executive motor system. Disease of the basal ganglia, which is associated with Parkinson's disease and is linked with programming and execution of motor tasks, does not interfere with the activation of action prototypes or the retrieval of images. Such motor prototypes or schemas are likely to be located in the cortex, possibly in the supplementary motor area.

Additional evidence comes from examining the interference effects of secondary tasks. Annett (1985, 1986) examined the possibility that motor imagery involves the motor output system by asking subjects to perform a secondary motor task whilst performing the imagery dependent task of explaining how to tie a bow. Results showed that the secondary task failed to inhibit imagery and thus the explanation. Inhibition of involuntary gestures, which frequently accompany the explanation, also did not interfere lending further support to the notion of a dissociation of visual imagery from the motor output system. A similar result was also reported by Johnson (1982) in a series of experiments on rehearsal of movements in motor STM. It was shown that the effect of imaginary movement was completely isolated from the primary motor output system but not from the system concerned with the representation of space.

Annett (1982, 1983, 1986, 1990) indicated that there is ample evidence that the verbal and nonverbal systems can function independently, but the dissociation is not complete. The two systems must be able to communicate and the key problem is what mechanisms mediate the translation between action and language. Figure 1.6 shows that the verbal and nonverbal systems are linked at the representational level and this link is referred to by Annett as the Action-Language (A-L) bridge. The A-L bridge refers to the notion that verbal instructions to act are conveyed from the verbal representational system to the motor executive system via a connection with the motor representational system. By contrast, verbal descriptions of an action are generated by first activating a non-verbal representation of the action and then the information is transmitted across the bridge to the verbal representational system from where it can activate the appropriate verbal executive output. Annett proposed that across the A-L bridge, two-way traffic is possible. This two-way traffic makes it possible to turn words into actions, that is to follow verbal instructions, and to describe actions in words.

In addition, Annett suggests that there is a common currency in which these transactions are carried out.

Annett (1985, 1986, 1990) argued that imagery is a crucial mechanism for the operation of the A-L bridge, and thus for mediating between the verbal system and the motor system. Effective verbal instructions are those which evoke clear images, and explanation of a motor task can only be clearly translated into the verbal code via imagery. Hence, according to the A-L bridge, the internal action representation is accessible to and modifiable by both the perceived actions of others and verbal instructions and descriptions. This representational system must be able to access output mechanisms so that perceived actions can be imitated and verbal instructions can be obeyed (Annett, 1989).

Annett (1982, 1994b) suggested that an approach to determining the properties of the A-L bridge is to carry out a programme of convergent experiments using the different paradigms illustrated in figure 1.6, which require translations in one direction or the other across the bridge. The above figure also shows a minimal set of basic concepts and the relationships between them as routes on a map, each route representing an experimental procedure. Annett identified eight types of experiments which are thought of as routes through his proposed model. Six of these types of experiments (routes 2, 3, 5, 6, 7, & 8) were indicated as six basic experiments that represent routes from the external world of objects and events, three of which, shown on the left side of the diagram, produce nonverbal actions and the other three, shown on the right of the diagram, produce verbal or written responses. These eight routes are:

<u>Route</u>(1):- Refers to any experiment in which an object or event (excluding human action or language) evokes a non-verbal response, e.g. a tracking task.

Route(4):- Refers to any experiment in which an object or event evokes a verbal response, e.g. a task of naming or describing something.

Route(2):- Refers to any experiment in which the input and output are non-verbal actions, e.g. a task of imitating human movements.

Route(5):- Refers to any experiment in which both input and output are verbal or linguistic. It represents the tasks of reading and shadowing and, where there is a time lag between input and output, verbal rote memory. Routes 2 & 5 are indicated to be analogous since they both represent imitative or echoic responses.

Route(3):- Refers to any experiment in which the input is verbal and the output is nonverbal, e.g. following verbal instructions to produce motor movement.

Route(6):- Refers to any experiment in which the input is nonverbal and the output is verbal, e.g. the task of giving running commentary or giving a description of actions. Routes 3 & 6 are indicated to be analogous routes involving transactions across the bridge.

Route(7):- Refers to any experiment in which an action is controlled by a stored verbal representation, e.g. a maze can be memorised as a series of left and right terms to guide the subject.

Route(8):- Refers to any experiment in which the subject is required to give a verbal description from a memorised or imagined representation of an action, e.g. the task of verbally explaining how to tie a bow (Annett, 1986, 1989). Routes 7 & 8 are indicated to be symmetrical and to involve memory.

Hence, it is apparent that routes 3, 6, 7 & 8 involve translations from the verbal to the nonverbal system or vice versa, and thus involve crossing the hypothetical A-L bridge.

The ALI model appears to have some implications by providing a framework for (Annett, 1994c):

(1) understanding imitation by means of the action prototypes which can be observed, stored and reproduced;

(2) understanding motor imagery since activation of a prototype may bring certain features of the action into consciousness without necessarily involving muscular activity;

(3) understanding the relationship between procedural and declarative knowledge. To explain how to do something, the relevant prototypes are activated and, via conscious images, enables the verbal system to make appropriate statements. This A-L bridge at the representational level also allows verbal instruction to be translated into action.

1.5.1. <u>A comparison of the ALI model to the WM model</u>

From the above discussion, it is clear that there is some resemblance between the ALI model and both the WM and dual coding models. The WM model was developed to account for the phenomenon of STM whereas the ALI model was developed as a means of coordinating various hypotheses to do with the role of cognitive processes in motor skill acquisition. The two models have a number of common features including a mechanism for motor imagery (Annett, 1995). In the WM model, imaginary actions are mediated by the VSSP. The ALI model proposes two channels one dealing with verbal input and output and the other dealing with perception and production of action. In this respect, it maps fairly well onto the

WM model and Paivio's model by assuming the relative independence of the verbal and nonverbal coding systems. In the original ALI model, the non-verbal channel was thought of as being specialised for perceiving and producing human action. To map onto the WM model, Annett (personal communication) indicates that this function or channel is widened to include all kinds of visuo-spatial information, but this is not too big a step since all action can only be represented meaningfully within a spatial context.

However, the key point of the ALI model, which the WM model does not attempt to address, is the concept of the A-L bridge discussed above. Also, the ALI model has a special feature, the involvement of motor processes in generating images. For instance, in translating procedural knowledge (knowing how to do something) into declarative knowledge (verbal explanation), action prototypes or schemas are activated. These are processes shared by both perceptual and motor systems and conscious images are generated which can be accessed by the verbal system through an associative link, the A-L bridge. Similarly, the action prototypes can be activated via appropriate verbal instruction leading to conscious images of action.

In addition, within each channel in the ALI model, a distinction is made between sensory representational elements and executive motor elements, but these are intimately linked, at least to the extent that representational processes are involved in execution. This perception/action link also has a parallel in the WM model in the proposed mechanisms for retaining material (Annett, 1995). Each of the WM slave systems comprises a sensory buffer that constitutes current conscious experience and which is maintained by a read-write loop. The AL is divided into a sensory passive store " inner ear" and a motoric rehearsal process "inner voice" or subvocalisation. Verbal material can be maintained if the inner voice continuously articulates, and thus refreshes the contents of the inner ear. The VSSP, as will be explained in the next chapter, is proposed (Reisberg & Logie, 1993) to comprise a sensory passive buffer "inner eye" and a motoric rehearsal process "inner scribe" that is probably related to the control of movement. Visuo-spatial information and images are maintained if the inner scribe rewrites material into the inner eye. Hence, the representational elements of the ALI model appear to correspond to the inner ear and inner eye, and the executive motor elements appear to correspond to the inner voice and inner scribe (Annett, personal communication).

The relationship between the sensory and motor elements of the ALI model are similar to those of the two subsystems in the WM model. Sensory activation can activate the motoric element and motor activation can activate the sensory element. Annett (personal communication) points out that, in the ALI model, this mutual activation is assumed to be subject to varying degrees of inhibition. Thus when watching an action, the tendency to produce the same action is inhibited. Such inhibition is imperfect when the watcher or listener is in a certain state of arousal. For instance, spectators have a tendency to emulate action on the field. A verbal counterpart may be the observation that some individuals cannot refrain from trying to finish a speaker's sentence. Carrying out an imaginary action may then be described as activation of the sensory aspects of the action whilst largely inhibiting the motoric aspect.

The third element of the WM model, the hypothetical CE, does not at first sight feature in the ALI model but Annett (personal communication) indicates that a possible role for the CE is in the activation of the motor elements. Thus, when sensory input leads to motor output or when motor activation leads to sensory activation or imagery, the CE is involved. Hence, the CE, Annett argues, is in effect the mechanism which controls the level of inhibition/excitation of the motor output system. In addition, the CE is presumably involved in the crossing of the A-L Bridge. Thus, whenever there is a translation from the language system to the action system or vice versa, the CE resources are assumed to be involved in such translations.

In summary, this chapter has provided a summary of the evidence which led to a distinction being made between LTM and STM. Some models which argued for the existence of STM and attempted to account for the STM phenomenon were considered. Then the argument for a specialised visuo-spatial STM component was considered. Three models which proposed a separate verbal and nonverbal STM systems were discussed which are the WM model, Paivio's dual coding model and Annett's ALI model. The nonverbal (visuo-spatial) system is thought to be involved in the generation and manipulation of visuo-spatial images and is proposed to comprise two elements, a representational element and an executive motor element. Motor secondary tasks have been found to interfere with visuo-spatial imagery tasks but not with verbal memory tasks, thus implicating the involvement of motor processes and probably the executive motor system in image generation and retention. However, it is not clear exactly why movement interferes with visuo-spatial memory and this issue will be discussed in detail when considering the role of movement in visuo-spatial STM in the next chapter.

Chapter 2

The Visuo-Spatial SketchPad (VSSP)

2.1. Introduction:

As mentioned in chapter 1, Baddeley & Hitch (1974) proposed that WM comprises an attentional supervisory system, the CE, and two modality-specific subsystems: the AL and the VSSP. The VSSP is assumed to be responsible for temporary processing and retention of visual and/or spatial material, and for setting up and manipulating visuo-spatial images.

The model of the AL is based on a variety of converging evidence and the specification of its characteristics is now relatively sophisticated largely due to the availability of a range of techniques for its investigation (see chapter 1, & Baddeley, 1986). In contrast, the characteristics of the VSSP are somewhat less clear, although some progress has recently been made and the VSSP is now the subject of several debates (Logie et al, 1990; Quinn, 1991). Logie & Marchetti (1991) indicated that the concept of the VSSP is less well developed than the AL both in theory and in application, although this trend is beginning to change (e.g. Morris 1987; Logie 1989; Quinn, 1988a, 1991). Quinn & Ralston (1986) indicated that in contrast to the AL, few experiments have been directed towards a firmer understanding of the VSSP. The VSSP is considered to be analogous to the AL insofar as it, too, holds information that can be actively rehearsed. The information held is visuo-spatial in nature, although no clear definition of this term has been put forward. Logie (1986), Halliday & Hitch (1988) and Logie & Baddeley (1990) pointed out that there is now a considerable body of literature which has clarified the role and characteristics of the AL, along with a range of techniques for its investigation. In contrast, the VSSP has received rather less attention, largely due to a lack of elegant and tractable techniques for its investigation. Whereas the study of AL and its properties has been greatly facilitated by the discovery and exploitation of experimental converging operations, an important obstacle to progress in understanding the VSSP is the difficulty of integrating evidence from various methods of investigation. This problem might reflect the fact that there are indeed many different visual stores. Alternatively, the tasks which have been used to investigate visual imagery and visual memory may encompass a variety of strategies, so that what is being seen in the various paradigms is a system being used in a wide variety of ways. However, over the last few years there has been an increase in the attention paid to this proposed visuo-spatial system and a number of techniques have been developed which have considerable potential for further exploration.

This chapter will start off with a description of the early development of the VSSP and evidence for a dissociation between the VSSP and the AL. Then a description of subsequent development of the VSSP will be provided emphasising studies that examined the role of movement in the VSSP. A description of some controversies and debates within the VSSP domain, particularly in regard to movement interference and the relationship between the VSSP and the CE, will then be provided. The chapter will conclude with stating the research problem and outlining the empirical work of this thesis.

2.2. Early development of the VSSP:

Within the WM framework, the initial studies that attempted to study visual WM made the assumption that the visual STM system is involved in forming and retaining visual images as well as in the retention of visual percepts. Thus, such a system is implied as having a role in visual perception as well as in visual memory or imagery. Baddeley (1986, 1988) indicated that the effort to link visual WM and visual imagery, and thus to incorporate a subsystem responsible for imagery into WM, began with an attempt by himself and Quinn to replicate a study by Atwood (1971) that was concerned with visual and verbal coding. A well known phenomenon that might implicate the VSSP, is the superior recall of highly concrete and imageable words in comparison with more abstract words. Paivio

(1971) has interpreted this result in terms of his dual coding theory of memory discussed in chapter 1. Paivio suggested that this is due to the possibility of dual coding with concrete words. With such words, subjects generate images of the items in addition to encoding them in a verbal form. With abstract words, it is difficult to generate an image of the item and only the verbal code is used. The 'dual coding' for concrete words, according to Paivio, leads to an advantage in recall for this material.

Hence, if the VSSP is involved in the apparent advantage of the recall of concrete words, then asking subjects to perform a concurrent visuo-spatial task should undermine this advantage. One such finding was reported by Atwood who required subjects to remember phrases which were either highly imageable such as "Nudist devouring bird" or abstract such as "The intellect of Einstein was a miracle". Presentation of the phrases was followed by a simple task of auditory or visual processing of digits. Atwood found that recalling the imageable phrases was disrupted by the visual processing task whereas recalling the abstract phrases was disrupted by the verbal processing task. This result was seen as promising since it is consistent with the idea of a specialised visual STM store that is involved in visual imagery and visual perceptual processing. However, several studies failed to replicate this finding including an unpublished study by Quinn (cited in Baddeley, 1986; & Logie & Baddeley, 1990) and a published study by Baddeley, Grant, Wight & Thomson (1975b).

Baddeley et al, in one experiment, asked subjects to retain high and low imagery word pairs such as "bullet-grey" or "idea-original" whilst concurrently performing a visuo-spatial tracking task. Results showed the traditional superiority in recall of the concrete material. However, the predicted interaction between concreteness and tracking was not found suggesting, as concluded by Baddeley et al, that the concrete-abstract difference was related to the richness of semantic associations for concrete words rather than reflecting a quality that facilitates a visual representation in STM. Such a conclusion would undermine Paivio's dual coding hypothesis (Logie & Baddeley, 1990). This interpretation by Baddeley et al was also supported by more recent results by Jones (1985, 1988) who demonstrated that 'ease of prediction' (the easiness of providing definitions, or alternative meanings for the word) was at least as good a predictor of recall performance as is imageability. This issue, however, appears to be controversial (see Logie, 1995 for a discussion).

Hence, although the concreteness effect appears to be robust and widely replicated, it does not seem to arise from the use of visual imagery and it did not seem to be a promising effect with which to explore the characteristics of the VSSP. Therefore, Baddeley and his associates moved away from this paradigm to a more fruitful approach involving the use of a set of techniques for studying visualisation which were reported by Brooks (1967, 1968). One of these techniques, the Brooks Matrix Task, has been used very frequently in subsequent investigations of the VSSP. In addition, this task is the main experimental task which has been used in this thesis to examine some hypotheses regarding movement interference in the VSSP. Therefore, before describing the subsequent literature on the VSSP, the Brooks Matrix task will be described in detail.

The Brooks Matrix Task

This task (Brooks, 1967) consists of two forms, a visuo-spatial form and a nonspatial, in fact verbal, form. In the visuo-spatial form, subjects are shown a 4x4 square matrix with the square on the second row and in the second column always designated as the starting square. Then, subjects are asked to visualise this matrix. Subjects are then required to listen to a set of 8 sentences describing the successive locations of the consecutive digits 1-8 in adjacent squares within the imagined matrix. Sentences are usually presented at the rate of one sentence per 2.5 seconds. As can be seen in Figure 2.1, these sentences ask subjects to place the digits in consecutive squares around the mental matrix. Subjects are requested to visualise the path described and then to repeat verbatim the sentences word for word using their visual imagery to aid recall. Each message (path) always started from the same starting square. In each test or message the first sentence was always the same, and the only way in which spatial messages differed was the sequence of transitions (up, down, right, left) from one square to another. These sequences were designed so that two different digits were never assigned to the same square by a message, and that a digit was never placed outside the matrix.

Brooks devised a complementary control condition in which similar sentences are used except that the polar spatial adjectives up-down, and left-right were replaced by the non-spatial polar adjectives quick-slow, and good-bad which makes retaining them reliant on rote verbal memory. These nonsense sequences were found to be more difficult than the spatial sequences, and in order to equate error rate, they were subsequently shortened from eight to five sentences. Figure 2.1 shows an example of the Brooks Matrix task in both its spatial and verbal forms:

		3	4
	1	2	5
		7	6
		8	

Spatial material

In the starting square put a 1.
In the next square to the **right** put a 2.
In the next square **up** put a 3.
In the next square to the **right** put a 4.
In the next square **down** put a 5.
In the next square **down** put a 6.
In the next square to the **left** put a 7.
In the next square **down** put an 8.

Nonsense material

In the starting square put a 1.
In the next square to the **quick** put a 2.
In the next square to the **good** put a 3.
In the next square to the **quick** put a 4.
In the next square to the **bad** put a 5.
In the next square to the **bad** put a 6.
In the next square to the **slow** put a 7.
In the next square to the **bad** put an 8.

Figure 2.1. Example of stimulus material (the Brooks Matrix task) developed by Brooks and subsequently used in experiments on the VSSP. (Adapted from Brooks, 1967).

Brooks found that when subjects had to read the spatial sentences, performance was impaired relative to when they had to listen to those sentences. The reverse was true for the nonsense sentences for which performance was impaired when subjects had to listen to the sentences relative to when they had to read them. Hence, visual imagery was suppressed by reading. Brooks suggested that the spatial sentences are remembered by means of visual imagery which shares some of the same processing apparatus as visual perception (reading), whereas the verbal sentences rely on verbal coding which tends to share the same system that is used in auditory perception (listening). Such results, along with other findings by Brooks (1968) imply a dissociation between the visuo-spatial and verbal systems. They also indicate (Logie, 1995) that there is a system that deals both with processing visual input and with generating and retaining images, and hence suggesting an overlap between visuo-spatial imagery and visuo-spatial STM.

Baddeley et al (1975b) followed up the Brooks (1967) study by requiring their subjects to listen to and recall the Brooks spatial and nonsense sentences, both under control condition and while performing a concurrent pursuit-rotor tracking task. The spatial sentences were disrupted by visuo-spatial tracking, but this tracking had no effect on the nonsense sentences which presumably rely on rote verbal memory. In another experiment, Baddeley et al showed that a concurrent imagery task, but not a verbal task, impaired visuo-spatial tracking. These results suggest (Baddeley, 1988) the operation of a specialised system that is separable from a verbal system, and that such system is involved in the production and control of arm movements.

Baddeley and his associates began, at this point, to refer to the VSSP as being responsible for visual imagery. The Brooks Matrix task appeared to involve a specialised visuo-spatial STM mechanism, but the evidence so far confounded two kinds of information, visual and spatial. The tasks used appear to be primarily spatial rather than visual, and it may be that the VSSP is specialised for dealing with spatial rather than visual or both visual and spatial material.

This possibility was examined by Baddeley & Lieberman (1980) who asked their subjects to perform the two Brooks Matrix tasks whilst concurrently performing one of two interference tasks. The first of which was auditory tracking which was assumed to be spatial nonvisual task since subjects were blindfolded whilst tracking a moving pendulum with a flash light. The second task, brightness judgement, was assumed to be a visual nonspatial task. It was shown that the nonvisual tracking task interfered with the spatial, but not with the verbal, version of the Brooks Matrix task. The visual brightness judgement task had no effect on the spatial matrix task but, unexpectedly, did interfere with the verbal Brooks task.

Baddeley & Lieberman also investigated whether imagery mnemonics are held and manipulated in a spatial WM store by examining the effect of a visuo-spatial tracking task on the use of imagery mnemonics. Subjects were required to learn lists of 10 abstract and concrete words relying on either rote verbal memory or on one of two mnemonic techniques, the peg-word method or the method of Loci. The peg-word method involves associating images of objects with numbers such as one-bun, two-shoe etc. The task then is associating the first word in the list with a bun and the second word with a shoe etc. Hence, if the first word in the list is a cigar, then the subject may imagine a bun with a cigar inside it. The method of loci is a location mnemonic that involves placing items TBR at locations on an imaged, familiar route. It is also assumed to be more spatial than a peg-word mnemonic. Results showed that concurrent tracking had no effect on rote verbal rehearsal but it interfered significantly with the use of the spatial mnemonic (method of loci). Tracking had a much weaker effect on the more visual peg-word mnemonic technique.

These results led Baddeley & Lieberman to suggest that the VSSP was primarily a spatially-based system rather than being purely a visual or visuo-spatial system. This system appears to be involved in retention of visuo-spatial material and in the use of imagery mnemonics, but since results showed that the VSSP can be disrupted by a spatial nonvisual task and not by a visual task, it was supposed to rely on spatial rather than visual coding.

2.3. Subsequent development of the VSSP

As pointed out above, Baddeley & Lieberman (1980) showed that concurrent tracking disrupted the Brooks Matrix task and the use of a location, rather than a visual, mnemonic and thus concluded that the VSSP was spatial rather than visual in nature. However, these results may be confounded by the fact that the Brooks Matrix, the location mnemonic, and tracking are all spatial. Interference may have been task-specific rather than being specific to one specialised mechanism. Tracking may have not interfered with the visual mnemonic because of the nature of the tasks rather than because of the nature of the VSSP. Baddeley & Lieberman, for instance, did not combine the visual brightness judgement task with the visual peg-word mnemonic. The VSSP (Logie, 1986,1991) might be involved in retaining both visual and spatial material. When it is processing spatial material, it will be disrupted by a secondary spatial task; and when it is processing visual material, it will be disrupted by a secondary visual task.

Logie (1986) investigated this possibility by examining the effect of a concurrent visual task on a visual imagery task and demonstrating an effect that is analogous to that of the irrelevant speech effect in the AL. Subjects were asked to retain a series of words relying either on verbal rote rehearsal or on the use of the visual imagery peg-word mnemonic technique which was described above when discussing the Baddeley & Lieberman experiments. In one experiment, subjects were concurrently presented with visual matrix patterns, which they had to classify. Results showed that this secondary task interfered with the visual mnemonics but not with verbal rote rehearsal. However, this secondary task involved classification and decision making and may have confounded the results by loading the CE.

In another manipulation by Logie, subjects were concurrently presented with irrelevant visual patterns on a screen and asked to try to ignore the patterns but to keep their eyes open and directed at the patterns on the screen whilst concentrating solely on remembering the list of words. Results showed a selective interference by the irrelevant visual patterns. The use of visual mnemonic was impaired by the irrelevant patterns whilst verbal rote rehearsal was not. In a further manipulation, irrelevant visual patterns were again shown to impair the use of visual imagery mnemonics but not verbal rote rehearsal, whereas irrelevant speech had the opposite effect. Irrelevant speech impaired verbal rote rehearsal but had no effect on the use of the peg-word mnemonic. This latter result of a double dissociation, supports the notion that separate processing mechanisms, the VSSP and the AL, are involved. In addition, these results demonstrate that irrelevant visual material has direct obligatory access to the VSSP whilst irrelevant speech has obligatory access to the AL. Hence, suggesting a close analogy of the VSSP with the AL.

Baddeley (1986, 1988, 1990) indicated that these results by Logie suggest that the earlier conclusion by Baddeley & Lieberman that the VSSP is spatial rather than visual was rather premature. The VSSP seems to represent either a multi-faceted system with visual and spatial dimensions, or possibly two separate visual and spatial systems. More discussion of this visual vs spatial debate will be provided in a subsequent section of this chapter. Baddeley also indicated that Logie's results are consistent with a concept of the VSSP that functions in a way that is parallel or analogous to the AL. The VSSP can be fed directly through visual perception or indirectly through the generation of visual images, and it also appears to be accessed directly by irrelevant visual information.

2.4. Dissociation between the VSSP and the AL

The studies described earlier in this chapter by Baddeley et al (1975b), Baddeley & Lieberman (1980) and Logie (1986) point to a dissociation between the VSSP and the AL. Verbal secondary tasks, such as irrelevant speech and articulatory suppression, were shown to interfere with verbal memory tasks but not with visuo-spatial memory tasks. In contrast, visuo-spatial secondary tasks such as tracking or irrelevant pictures were shown to have the opposite effect. In the literature, several other studies have demonstrated this double dissociation between the two slave systems of WM. For instance, Farmer et al (1986) showed that articulatory suppression impaired performance of the verbal reasoning task, devised by Baddeley (1968) and discussed in chapter 1, but had no effect on a spatial reasoning task known as the Manikin test. In contrast, a presumably spatial suppression task involving tapping round four spatial targets, was shown to impair performance of the spatial reasoning task but to have no effect on the verbal reasoning task. These results were taken as evidence for a VSSP that is dissociable from the AL.

Similarly, Logie et al (1990), using a matrix patterns span task devised by Wilson, Scott & Power (1987), showed that this visual memory span task was impaired by a concurrent visuo-spatial imagery construction task but not by a concurrent verbal task (mental arithmetic). The opposite pattern of interference occurred with a verbal memory span task which was impaired by the concurrent verbal task but not by the concurrent visual imagery task. In another experiment, the visual span task was impaired by the Brooks spatial matrix task whilst the verbal span task was impaired by the verbal version of the Brooks task.

Evidence for this dissociation between verbal and visual WM comes also from studies on neuropsychological patients. For instance, Hanley, Young & Pearson (1991) reported a patient (ELD) with right hemisphere damage who was described as having a deficit in the VSSP. This patient had problems with mental rotation and other spatial tasks such as the Corsi blocks and the Brooks Matrix, but had no difficulty with verbal STM tasks and showed evidence of phonological similarity and word length effects. Farah, Hammond, Levine & Calvanio (1988) reported a patient (LH) who was severely impaired on visual imagery tasks, but performed normally on spatial imagery tasks and had a normal verbal STM. Baddeley et al (1991) reported an Alzheimer patient whose performance was impaired on tests of visual STM but not on tests of verbal STM. Another patient showed the opposite pattern of impairment. Similarly, Grossi & Becker (1994) described Alzheimer patients with spared visuo-spatial STM and impaired verbal STM. Ruchkin, Johnson, Grafman, Canoune & Ritter (1992) presented further evidence from studies of brain activities in normal subjects for the distinction between verbal and visual WM. Finally, Wang & Bellugi (1994) found a double dissociation in the performance of two genetically defined groups on temporary storage for phonological and for visuo-spatial information. Subjects with Williams syndrome performed significantly better on a verbal STM task (digit span) than on a visuo-spatial STM task (Corsi blocks). Subjects with Down syndrome showed the opposite pattern of impairment, and thus supporting earlier indications by Bihrle, Bellugi, Delis & Marks (1989) regarding these two groups.

2.5. A model for the VSSP:

There was an early debate about the status of the VSSP and whether there is any need to postulate a specialised visuo-spatial system separate from the CE (e.g. Phillips & Christie, 1977b; Phillips, 1983). However, from the studies described above and other studies that will be discussed shortly, and from recent indications by some pioneers in this field (e.g. Baddeley, 1992a&b; Logie, 1993, 1995; Quinn, 1991, 1994) there is now little doubt that the VSSP exists as a functionally separable system within the WM model, although its characteristics are the subject of various debates as will be discussed later in this chapter.

As pointed out in chapter 1, the model for the AL was based on a variety of converging evidence and it appears to be relatively sophisticated. The VSSP has been thought of as complementary to the AL (e.g. Baddeley, 1986, 1990; Della Sala & Logie, 1993; Logie, 1989, 1991; Reisberg & Logie, 1993; Toms, Morris, & Foley, 1994). This view has been supported by results demonstrating the existence of some phenomena similar to those associated with the AL some of which are:

1) Irrelevant visual input:

As previously mentioned, Logie (1986) demonstrated that unattended visual material has a privileged access to the VSSP which is similar to the privileged access by unattended speech to the AL. This result is consistent with the notion that the VSSP is involved in processing visual perceptual input as well as setting up and manipulating visual images. Similar results have been reported in the literature. For instance, Johnson (1982) demonstrated that the biasing effect of an imagined movement was removed by watching a visual display. Images of movement appear not to be a function of the motor output system but they require a capacity of the visual processing system. Smyth & Pendleton (1990) showed that recall of bodily movement patterns was affected by simply watching similar movements during a retention interval. Logie & Marchetti (1991) showed that an irrelevant pictures task disrupted maintenance of a visual, but not of a spatial, memory task, and indicated that the VSSP involves a passive visual store that is susceptible to interference by irrelevant visual input.

Recently, Quinn & McConnell (1994) demonstrated that an irrelevant visual stimulus, a dynamic visual noise, selectively interfered with the use of visual mnemonics, but not with verbal rote rehearsal. Toms et al (1994) showed that exposure to an irrelevant visual input during encoding or during maintenance, selectively disrupted performance on the spatial, but not on the verbal, version of the Brooks Matrix task. They interpreted this result as suggesting that irrelevant visual material has obligatory access to a passive visual buffer, although the primary memory task was primarily spatial rather than visual. Toms et al indicated that this result suggests that visual and spatial elements of WM work in tandem, comprising a constellation deployed whenever visuo-spatial processing is required. This result by Toms et al is in contrast to the result by Baddeley & Lieberman (1980) who found no disruption by a secondary visual task, brightness judgement, of performance on the Brooks Matrix task. In this regard, Toms et al indicated that the brightness judgement task probably does not involve visual material of sufficient visual complexity to overwrite storage of visuo-spatial material. Brightness judgement was, however, found by Quinn (1988a) to interfere with the Brooks Matrix task, but since it also interfered with the Brooks verbal version, a conclusion of visual interference was questionable. Interference was suggested to be related to the brightness judgement task loading the CE.

2) Visual similarity effect

There is some evidence that visual confusions occur when subjects try remembering visually presented material that are visually similar to one another (e.g. Hue & Ericsson, 1988). This suggests (Logie, 1991) that visual information is retained by the system with many of the raw visual features intact. Frick (1988) presented evidence which supports the idea that visual confusions arise because of the nature of the code stored in visual WM. Logie (1988) demonstrated visual similarity effects with little likelihood of visual lexical involvement. Visual similarity effect occurred with or without articulatory suppression, and thus subjects did not rely on verbal recoding but rather on a visual code. Walker, Hitch & Duroe (1993) demonstrated a visual similarity effect in recall of visually similar or dissimilar quasi-random block patterns of letter stimuli. In some conditions, subjects were required to suppress their articulation during presentation of the stimuli. It was shown that performance was unaffected by articulatory suppression and hence ruling out the possibility that this similarity effect was an artefact of the use of phonological or semantic coding. Smyth & Scholey (1994b) observed that spatial span was reduced by the attempt to visually encode highly confusable items or arrays.

Hitch, Halliday, Schaafstal & Schraagen (1988) demonstrated that young children have more difficulty in immediate serial recall of a sequence of pictures of visually similar objects than in recalling a sequence of visually distinct items. In another study, Hitch, Woodin & Baker (1989) showed that older children also show the same effect but the visual similarity effect occurs only if these children are prevented from using objects names at encoding by means of articulatory suppression. It is argued that, unlike younger children who have an underdeveloped verbal coding system, older children can use both visual codes and verbal codes; but tend to rely on verbal codes unless prevented from doing so by articulatory suppression. Logie (1995) argued that visual similarity effects indicate that the system involved relies on visual codes, and that although these effects do appear, they are undermined by the tendency in normal adults to rely on verbal coding.

3) Visual recency effect:

As pointed out in chapter 1, one of the important findings in the free recall of verbal material was the recency effect. There is some evidence for visual recency effects that can not be attributed to verbal labelling of the stimuli and seem to reflect the operation of a visual STS. Phillips & Christie (1977a&b) used a paradigm involving the presentation of a sequence of square matrix patterns. Patterns were formed by lighting randomly selected cells in a 4x4 matrix. Usually, memory for the patterns was tested in reverse serial order. This involved presenting the original sequence in reverse serial order with the subject indicating whether a given item had appeared in the previous sequence. Phillips & Christie (1977a) reported a recency effect in which the last pattern in a sequence of patterns was significantly better recognised than any other earlier pattern. Phillips (1983) argued that the one item recency effect may reflect the capacity of visual STM whereas the other items are retained less efficiently in a LTM store. Phillips & Christie (1977b) examined the effect of carrying out some secondary tasks during a maintenance interval. The one-item recency was removed by a number of interpolated tasks including mental arithmetic which is not a visuo-spatial task. This latter result was interpreted as suggesting that visualisation requires general purpose resources (i.e. the CE) rather than a specialised visuo-spatial STS.

Broadbent & Broadbent (1981) disputed the above interpretation by Phillips & Christie. They examined recency effect in visual STM using patterns that were less regular than those used by Phillips & Christie. They also used a forced-choice recognition procedure, probing items from different positions in the series of patterns. A marked recency effect was demonstrated as being evident over the last three items of the series and not just the final item as shown by Phillips & Christie. In addition it was shown that this recency effect was unaffected by a secondary task performed during a maintenance interval although overall performance was affected. The overall levels of performance were also higher than they were for the Phillips & Christie tasks which could account for the difference in the number of recency items. The advantage for the recency items appears to be with the involvement of a specialised visual store, and it was concluded that the obtained recency effect reflected the operation of such system. Further evidence against Phillips & Christie's interpretation was presented by Avons & Phillips (1987) who showed that in the Phillips & Christie's tasks, subjects could use verbal labelling and semantic categorisation.

Moreover, Hitch et al (1988,1989) demonstrated that in both young and older children, visual WM is responsible for a final-item visual recency effect in a task involving recall of a series of drawings in reverse temporal order. In general, it appears from these studies on visual recency effects that this recency effect reflects the operation of a specialised visual STS (Halliday & Hitch, 1988).

4) Other phenomena:

In addition to the above phenomena which, to some extent, suggest a close analogy with the AL, Smyth & Scholey (1992, 1994b) attempted to examine whether there is an analogy to the word length effect in visuo-spatial WM. As mentioned in chapter 1, it has been shown in studies of the AL that the length of words TBR affects the size of memory span. The number of words that can be maintained and recalled depends on how long it takes to say the words. This word length effect is attributed to relationships between the rate of rehearsal of verbal material and the time it takes to speak or articulate the words being rehearsed. Verbal span is decreased if the length of time required to say the items increased. The rate at which people are able to articulate also predicts the number of items they will be able to recall. Smyth & Scholey indicated that spatial memory span may also involve an internal rehearsal system linked to overt responding, and if there is a strong analogy between maintenance in the AL and the VSSP, then movement time between spatial targets should predict the number of spatial locations that are to be recalled.

Smyth & Scholey (1992) used the Corsi blocks task (De Renzi & Nichelli, 1975) as their spatial span task. This task involves the use of a set of nine small blocks placed in a quasi-random manner on a board. The tester taps a series of blocks and the subject is required to remember the sequence and recall it in order. They examined whether rehearsal time could be an important determinant of recall by using an individual differences approach in which the rate at which an individual can produce hand and eye movements, which was assumed to correspond to articulation rate, was used to predict spatial span. Results showed that the time taken by an individual to make speeded movements to spatial locations can not predict spatial span performance. There is no simple analogy between verbal and spatial spans in which timing of output is linked to the rate of overt rehearsal.

Smyth & Scholey (1994b) using the same task examined whether movement time has the role of word length by manipulating movement time. If there is an analogy to the word length effect, then increasing the length of time it takes to make movements to spatial targets would affect the number of items that could be recalled in order. The time taken to move between spatial targets is varied by altering the size of targets and the distance between them. Results showed that spatial span can not be predicted by movement time. It is concluded that it may not be possible to find an analogy of the word-length effect in spatial span due to the nature of the stimuli, and thus this would not count as a strong evidence against a response-based rehearsal process in the VSSP. The issue of maintenance rehearsal in the VSSP will be thoroughly discussed in later sections of this thesis.

2.6. Functions of the VSSP

Before describing further development of the VSSP and some current debates about its characteristics, the following is a brief account of what functions the VSSP might serve in everyday tasks.

It has been indicated (Baddeley, 1990; Morris, 1986a) that the spatial system is important for geographical orientation and in the development and updating of one's cognitive map of the environment. For instance, Moar (1978) found that tracking interfered with subject's cognitive representation of the relationship between locations in a familiar city whereas articulatory suppression had no effect. Logie (1993) described evidence that learning routes around an unfamiliar environment may rely on the VSSP. In addition, patients with an impaired VSSP (e.g. Hanely et al, 1991) showed difficulty in learning new spatial relationships in the world. They could remember places and routes they knew before their brain lesions but they can not learn new ones. The VSSP appears also to be useful for chess expertise (Saariluoma, 1991) and mental arithmetic particularly for expert abacus users (Hatano & Osawa, 1991).

The VSSP is also important in planning spatial tasks. Tasks involving visuo-spatial manipulation have been an important component of intelligence test batteries, and have been used as selection tools for industrial professions where visuo-spatial planning and manipulation are assumed to be important such as engineering and architecture. Logie, Baddeley, Mane, Donchin & Sheptak (1989) studied the role of the VSSP in complex tasks involving several components and examined whether this role changes with increased experience on these tasks. They studied the role of the VSSP in learning a complex computer game "Space Fortress" which relies on perceptuo-motor skills and accurate timing of responses as well as short and long term strategic decisions. Results showed that during early stages of training, important components of the game were interfered with by secondary visuo-spatial, but not by verbal, tasks. After increased practice, the selective interference by the visuo-spatial tasks disappeared suggesting that the VSSP plays an important, but changing, role in training and learning of complex perceptual-motor tasks. This approach is indicated (Logie & Baddeley, 1990) to have potential for a fairly detailed mapping of the component skills involved at various stages in training, and it encourages the applicability of secondary-task procedures in this context.

In addition to these functions, the VSSP has been implicated in the following skills (Logie, 1993, Della Sala & Logie, 1993):

1) Reading:

Evidence for the involvement of the VSSP in reading was provided by the work of Brooks (1967, 1968) described at the outset of this chapter. Brooks (1967) found that performance was poorer when subjects had to read series of 8 sentences which require constructing a visual image of a 4x4 matrix. Listening to the sentences did not impair performance. This suggests an overlap in the cognitive processes involved in reading and those involved in imaging. The VSSP is also assumed to play a role related to "place-keeping" while reading text and retaining accurate information about the spatial layout of the text.

Recently, Kruley, Sciama & Glenberg (1994) presented evidence that the comprehension of illustrated text makes use of the VSSP. Comprehension of texts that are accompanied by pictures was shown to disrupt performance of a spatial, but not of a verbal, STM task. These results were described as consistent with the assumption that illustrations accompanying a text encourage the formation of a spatial mental model using the VSSP.

2) <u>Visual imagery & mnemonics:</u>

The use of visual imagery has been shown (e.g. Paivio, 1971) as an effective method of enhancing memory. As has been indicated throughout this chapter, there is a strong link between the VSSP and the setting up and manipulation of visual images. It has been demonstrated (e.g. Logie, 1986; Quinn & McConnell, 1994) that the use of the visual peg-word mnemonic relies on the VSSP suggesting that this system plays an important role in imagery mnemonics.

3) <u>Planning & control of movement:</u>

As will be discussed when examining the role of movement in the VSSP, many studies (e.g. Quinn & Ralston, 1986; Quinn, 1991; Smyth & Pendleton, 1989, 1990) have pointed to a link between movement control and retention of visuo-spatial images. There appears to be an overlap or a link between the cognitive functions involved in representing sequences of movements in space and those involved in arm movements, and possibly eye movements (e.g. Idzikowski, Baddeley, Dimbleby & Park, 1983). These indications are consistent with some neuropsychological data (e.g. Anderson, Essick & Siegel, 1987) indicating that neural activity related to motor planning for movement towards an object, but not to the actual production of movement, is associated with neural activity which is implicated in constructing mental representations of the location of objects in space. In short, it seems that a spatial-motoric component of WM is associated with the planning and control of spatial movement.

2.7. Characteristics of the VSSP, some issues & debates:

Work on the VSSP has sufficiently advanced to have generated a number of debates regarding its characteristics. Most of these debates centre around the following issues:

2.7.1. The VSSP & the CE

As pointed out earlier when discussing visual recency effects in the VSSP, Phillips & Christie (1977a,b) raised the question of whether there is any need to postulate the existence of a specialised visuo-spatial subsystem separate from the CE. Their experiments on memory for visual patterns suggested that visualisation utilises general purpose resources, not a separate subsystem, so that any mentally demanding task will compete for resources. For instance, visualisation was suppressed when subjects were asked to add aurally presented digits. The more demanding the interpolated task is, the greater the forgetting. A result they interpreted as suggesting that retention of the visual pattern was dependent on a CE system rather than a specialised VSSP.

As explained earlier, in establishing a dissociation between the VSSP and the AL, researchers followed a double dissociation approach. This approach involves demonstrating that a verbal secondary task interferes with a verbal, but not with a visuo-spatial, memory task, and the opposite pattern should occur when using a visuo-spatial secondary task. Baddeley (1988) and Logie et al (1990) indicated that this approach works well if only two systems are considered, but the WM model proposes three mechanisms. Logically, to demonstrate the existence of three systems, a triple dissociation, in an experiment with nine contrasting conditions, is needed. However, since the CE is different both in nature and complexity from its slave systems, a triple dissociation would almost be impossible to achieve. A solution proposed by Logie & Baddeley (1990) is to use the procedure of converging operations which has been successful with the development of the AL. This procedure refers to accumulating evidence from various experimental paradigms in the hope of a more coherent view. The following section will briefly discuss some studies that contributed to the body of converging evidence for the VSSP, particularly to its separation from the CE.

Farmer et al (1986) considered the suggestion by Phillips & Christie (1977a&b) that if a specialised VSSP exists, then it should be possible to devise a secondary task that places heavy demands on this system but not on the CE. Such a task would interfere with visualisation but not with tasks that do not load the VSSP. Farmer et al devised a spatial tapping task that was subsequently used by many researchers to investigate the VSSP. This task, which was considered to be a spatial analogue to the articulatory suppression technique, involved continuously tapping four metal plates positioned in a square arrangement. This task was thus considered to load the VSSP but not the CE.

Farmer et al identified the Baddeley (1968) verbal reasoning task, which was explained in Chapter 1, as a candidate for heavy CE involvement. This task was combined with either articulatory suppression or the spatial tapping task. The spatial suppression task had no effect on verbal reasoning whilst articulatory suppression had a small disruptive effect that was confined to the most difficult problems. Farmer et al also examined the effects of these two secondary tasks on a spatial reasoning task known as the Manikin test which was assumed to rely on visuo-spatial processing. Results showed that articulatory suppression had no effect but spatial tapping had a substantial effect on performance. Since articulatory suppression did not lead to a substantial impairment of the verbal reasoning task, this task was taken as relying on the CE rather than on the AL. Therefore, the overall results show something of a dissociation between the CE and the VSSP.

A further study by Logie et al (1990) investigated the suggestion by Phillips & Christie (1977a&b) that the visual recency effect may rely on the operation of the CE plus the use of the AL rather than on a specialised VSSP. Phillips & Christie based their conclusion on the finding that visualisation was suppressed by mental arithmetic which makes it unclear whether visualisation occurs in a specialised VSSP or requires CE resources. Logie et al argued that the nature of the interpolated task is perhaps the central factor in determining any disruptive effects. Mental arithmetic may involve various memory codes, and thus they closely examined the link between this task and visuo-spatial WM.

Logie et al, used, as their visual memory task, a visual memory span task devised by Wilson et al (1987). As their verbal STM task, they used a letter span task which was a verbal analogue of the visual span task. These two memory span tasks were combined with either mental arithmetic or with a visual imagery secondary task. Concurrent mental arithmetic led to a small but significant disruption of the visual span task. The concurrent visual imagery task led to a small but significant disruption of the verbal span task. The most striking result, however, was the clear differential disruption of visual span by concurrent visual imagery, and of verbal span by concurrent mental arithmetic. There was a general processing load involved but it was relatively small relative to the clear interaction. Such clear cross-over interaction was taken as consistent with the assumption of separate visuo-spatial and verbal subsystems that are also dissociable from the CE. Logie et al concluded that their results support the existence of a separate, specialised VSSP that also requires a certain amount of monitoring by the CE. This VSSP appears to be involved in visualising and in retaining visually presented patterns.

These indications by Logie et al (1990) were supported by more recent studies. For instance, Ruchkin et al (1992) indicated, from some event-related brain potentials (ERP) data, that their ERP data are consistent with behavioural data of Logie et al supporting the existence of a specialised VSSP. Similarly, Parr (1992), using a delayed matching procedure, concluded that her results were consistent with those of Logie et al by supporting the view that a passive visuo-spatial subsystem, rather than CE resources, is responsible for temporary maintenance of a visuo-spatial stimulus.

2.7.2. Visual or Spatial

In considering the cognitive functions involved in temporary visuo-spatial processing, do they reflect just one mechanism having both spatial and pictorial components, or are there separate mechanisms or sketchpads for spatial and for visual material? Baddeley (1992a) indicated that the VSSP is a complex system having both visual and spatial components, but components that seem to be difficult to tease apart experimentally. Logie (1993) indicated that there is some debate as to whether the VSSP is best thought of as a single system, or as two complementary systems dealing respectively with visual and with spatial material (e.g. Baddeley & Lieberman, 1980; Logie & Baddeley, 1990; Smyth & Pendleton, 1989; Logie, 1986, 1989; Quinn 1988a; & Reisberg & Logie, 1993). Logie pointed out that there is also some debate as to whether or not the systems involved function independently of some kind of central processing or focused attention. Evidence is growing in favour of two separate mechanisms that can act in concert, although the link between these mechanisms and the CE is still unclear.

As mentioned earlier in this chapter, Baddeley & Lieberman (1980) found that the Brooks Matrix task was disrupted by nonvisual tracking and thus suggested that the VSSP was primarily spatial rather than visual. However, such a conclusion was later shown by Logie (1986) to be premature. Logie showed that the VSSP may have a visual component by demonstrating that the use of visual imagery mnemonics is disrupted by concurrent presentation of irrelevant visual material. It thus appears that depending on the demands of any given task, the VSSP may show predominantly visual or spatial characteristics (Baddeley, 1988). Tasks involving purely spatial coding will be more sensitive to spatial disruption and tasks involving purely visual coding will be more sensitive to visual disruption. Within the literature (e.g. Farah et al, 1988; Logie, 1995) spatial information is associated with information relevant to the location of objects in space and the spatial relationships among them, and also with movement through space such as scanning or moving from one position to another. Visual information usually refers to properties of objects such as their colour, shape, or brightness; and a visual representation is associated with retention of static visual arrays.

Further evidence for a visual component of the VSSP comes from other studies demonstrating the effects of irrelevant visual input, visual recency, and visual similarity, which were discussed earlier in this chapter. In addition, further evidence for a spatial component of the VSSP comes from studies (e.g. Quinn, 1988a&b, 1991, 1994; Smyth & Pendleton, 1989, 1990) that have shown that spatial memory tasks such as the Brooks Matrix were disrupted by concurrent movement suppression tasks such as arm movement or tracking. These studies will be discussed when examining the role of movement in the VSSP.

Therefore, it appears that there is evidence for a temporary spatial store that also is involved in movement tasks; and another temporary visual store that also is involved in processing visual input. However, it is not clear whether it is a single system that deals with both visual and spatial information or whether two separate systems are involved. This distinction between visual and spatial processing has a precedent in the literature. For instance, Jones (1976) has shown that spatial position in an array appears to be remembered quite independently from object identity. Also, Allport (1977) found independence in the reporting of letters in an array and the reporting of their position in an array. Support for the visual-spatial distinction also comes from the visual imagery literature. For instance, Engelkamp (1988, 1991) has shown that images that are enacted are better remembered than those that are not. For example, miming the act of smoking a pipe, or even imagining miming this act, leads to better memory retention than simply imagining a static image of someone smoking a pipe.

In addition, the distinction between visual and spatial processing is consistent with neuropsychological evidence. For instance, Farah and her colleagues (Farah, 1988; Farah et al, 1988) have argued for a dissociation between visual and spatial components of mental imagery. Farah et al (1988) reported a patient (LH) who appeared to have a deficit in the performance of visual imagery tasks but did not show such deficit with spatial imagery tasks. This patient had severe damage to the temporal and occipital lobes but not to the parietal regions. He had normal language and verbal IQ but showed a pattern of impairment on a range of visual imagery tasks such as giving the colour of common objects and judging the length of animals' tails. In contrast, this patient performed normally on spatial imagery tasks such as the Brooks Matrix task and mental rotation tasks. Farah et al concluded that imagery has related but separable visual and spatial components. These two groups of visual and spatial imagery tasks appear to tap independent components of imagery representation that are shared with visual and spatial perception respectively.

A patient (ELD) who seem to have the opposite deficit was reported by Hanely et al (1991). This patient had an intact visual imagery but had a deficit on spatial imagery tasks after a right hemisphere aneurysm. The patient was shown to perform well on the visual imagery tasks used by Farah et al, but his performance was impaired on spatial tasks such as the Brooks Matrix and mental rotation tasks. These two patients appear to provide a double dissociation between visual and spatial components of mental imagery.

Inner eye-Inner scribe:

Relevant to the visual-spatial distinction is the suggestion by Logie (1989) that visuo-spatial STM might comprise two functions, a passive visual store and an active rehearsal process, with this latter function related to the control of movement and is also akin to some form of mental scanning of the visual representation. Logie indicated that this proposal is in close analogy to the AL which is thought to comprise two functions, a passive phonological store and an active articulatory rehearsal process. Furthermore, Logie pointed out that the passive visual store is accessed directly by irrelevant visual input whereas the active rehearsal process should be suppressed by spatial movements such as tracking. In this case the analogy is with the effects of articulatory suppression in verbal WM. However, Logie argued that this analogy is speculative and there is a danger in pushing the analogy with the AL too far.

Similar to this proposal by Logie, is the proposal by Reisberg & Logie (1993) of a partnership in visual imagery between an *inner eye* and an *inner scribe*. The inner eye refers to the passive visual store whilst the inner scribe refers to the active rehearsal process that is related to movement retention and control. Reisberg & Logie indicated that for the AL and auditory imagery, a partnership exists between a sensory element (inner ear) and a motoric element (inner voice). As explained in chapter 1, the inner ear and the inner voice refer respectively to the two components of the AL, the passive phonological store and the active subvocal rehearsal process. Contents of the store decay but subvocalisation can be used to refresh the store's contents. Verbal material can be maintained indefinitely if the inner voice continuously repeats the current contents of the sensory buffer to the inner ear. The mechanism is made plausible by the demonstration of articulatory suppression, that is suppressing the inner voice (subvocalisation) by continuously repeating irrelevant words such as "the, the, the....". This partnership in verbal WM is well supported by evidence as explained in chapter 1.

Reisberg & Logie proposed that a similar partnership between sensory and motoric elements exists for the VSSP and visual imagery. They proposed that the VSSP could be divided into two stores, one visual and the other spatial or motoric. The visual element or buffer is called the 'inner eye' which holds static visual representations and is linked to the visual perceptual system. The spatial-motoric element is called the 'inner scribe' which can retain and rehearse a sequence of movements and is linked with the mechanism of motor control and planning. The inner scribe can feed or write information into the inner eye in order to prevent decay or to allow manipulation and transformation of images. The mechanism for the inner scribe is not as clear as that of the inner voice (subvocalisation) but it presumably involves the generation of visual images. This partnership is indicated by Reisberg & Logie to be plausible but still speculative and it is proposed to be an important focus for future research. In regard to the relationship between both the inner eye and the inner scribe and the CE, Logie (1993) argued that it is possible that some form of attentional resource is required in some of the operations attributed to these two elements.

Logie & Marchetti (1991) provided evidence consistent with separate visual and spatial WM systems and with the above proposals. Subjects were required to retain information from one of two kinds of visually presented stimuli. The visual task comprised retaining static arrays of colour hues and subjects had to remember the shade of the colour presented in a particular location on the screen. The spatial task required retaining the sequential order in which a series of squares was presented at different locations on the screen. Performance on the visual task was disrupted by presentation, during a maintenance interval, of a series of irrelevant pictures, but not by performing a spatial movement task. In contrast, the spatial task was disrupted by an interpolated arm movement task, but not by the irrelevant pictures. Thus, providing a double dissociation between visual and spatial components. These results were interpreted in terms of Logie's (1989) proposal. Maintenance of the colour hues was the responsibility of the passive visual store which is accessed directly by irrelevant pictures and thus causing a disruption of its contents. Maintenance of a series of movements, on the other hand, was the responsibility of the active rehearsal process which is related to movement control. Carrying out a spatial movement task during the retention interval caused disruption of this rehearsal process.

More recently, Logie (1995) asserted the separation between visual and spatial WM. In his modified model of WM, Logie referred to the inner eye as the 'visual cache'. The inner scribe, spatial WM, provides a means of "redrawing" the contents of the visual cache, offering a service of visual and spatial rehearsal, manipulation, and transformation. Logie argued that there seems to be a strong evidence that spatial and visual information are processed separately, but that they are brought together to form a global representation of space. This representation seems to be available for manipulation in the form of visual images and there are links between that representation and the planning and control of movement to targets.

2.7.3. Role of Movement

The idea that the VSSP is involved in the control of movement stems from the suggestion that the VSSP comprises two complementary components, one spatial and the other visual. As mentioned above when discussing the visual vs spatial debate, spatially-determined motor tasks have been shown to interfere with spatial, but not with purely visual, information and images, whereas purely visual secondary tasks have been shown to lead to the opposite pattern of interference. Thus, a distinction has been drawn between a visual and a spatial code, but no explicit and specific definition of a spatial code has been put forward. However, this visual vs spatial debate has led some researchers to look for a more explicit definition of spatial processing.

Results demonstrating disruption of spatial memory tasks by spatial movement or tracking tasks (e.g. Baddeley et al, 1975b; Baddeley & Lieberman, 1980) indicate that a spatial code is involved in the representation of items occupying distinct spatial locations. Quinn (1988a, 1990, 1994; Quinn & Ralston, 1986) indicated that a major shortcoming of the VSSP is that there are no sufficiently specified definitions of spatial coding and processing. It is implicitly defined by the nature of the tasks assumed to interfere with it. So movement is assumed to interfere with spatial processing and the processing itself is assumed to involve movement processes. For instance, Baddeley & Lieberman implicitly defined spatial processing in an operational manner: it is the process that underlies the subjects' ability to track a pendulum while blindfolded. However, as tracking tasks involve movement to targets in space, this has led to various studies being conducted to examine the involvement of movement in the VSSP and the sorts of movement that cause interference in the VSSP (e.g. Quinn & Ralston, 1986; Smyth & Pendleton, 1989).

Thus, more delineation of the cognitive processes that contribute to the organisation of the spatial code appeared to be required. In addition, Baddeley (1992a) indicated that it is less clear what process underlies the active rehearsal of visuo-spatial imagery, playing the spatial equivalent to the role of subvocalisation in verbal WM. One possibility is that such rehearsal is based on the system involved in controlling eye movements but the evidence is not conclusive.

Eye movements have been implicated as playing a part in the organisation of the spatial code (e.g. Idzikowski et al, 1983). However, other evidence indicate that it is not just movement of the eyes that perform this function. For instance, Baddeley et al (1975b) and Baddeley & Lieberman (1980) used movement tasks that involved arm movements such as pursuit rotor tracking. In general, it appears that movement of some kind has a crucial role to play in spatial coding. The following is a brief description of some studies that investigated this issue.

Eye movements have been indicated as an important factor in either setting up images or in scanning them (Bergstrom & Hiscock, 1988 for a review). Idzikowski et al, (1983) attempted to apply an eye movement suppression technique to the study of visual imagery and thus to investigate whether eye movements could serve as a rehearsal function in the VSSP that is analogous to the function of articulation in the AL. They examined the effect of voluntary or involuntary eye movements on the verbal and spatial forms of the Brooks Matrix task. Involuntary eye movements were initiated by spinning the subject around in a chair resulting in post-rotational nystagmus. Voluntary eye movements involved the subject following a sinusoidally moving target across a computer screen. The verbal Brooks task was not affected by any of these tasks. But voluntary eye movements disrupted performance of the spatial Brooks task whilst the involuntary eye movements had no effect. Also, there was no effect when the eyes were held stationary whilst the screen background moved and thus changing the visual input. Thus, control of eye movement seem to play an important role in imagery. However, Idzikowski et al acknowledged that it could be the control of attention rather than the control of eye movements. Movement of attention across the display screen may have been the crucial factor rather than movement of the eyes.

Quinn & Ralston (1986), using unseen arm movements rather than eye movements, examined the sorts of movement relevant to the spatial code and a possible separation of movement and attention. They used the Brooks matrix spatial task as their primary task. Subjects, during encoding, had to make unseen arm movements that were either compatible with the directions given by the Brooks sentences, or were incompatible. Subjects made these arm movements around a square matrix taped to the table in front of the subject. This matrix and the subject's arm were covered so as to prevent the subjects from seeing their arm movement. Incompatible movement disrupted memory for the Brooks Matrix but compatible movement did not. In another experiment, incompatible movement was found to be disruptive even if it was passive and thus minimising the contribution of the

CE. Passive movement refers to the experimenter holding the subject's arm and moving it for them. This suggests that movement per se, rather than attention to movement, caused the disruption.

From these results Quinn & Ralston indicated that movement should be given prominent reference in the definition of spatial coding and in the description of the characteristics of the VSSP. However, as indicated by Logie & Baddeley (1990), Quinn & Ralston did not include the verbal form of the Brooks task as a control memory task. It would have been more convincing to show that the verbal form was insensitive to movement interference, since even with passive movement subjects may covertly monitor the movement of their hands.

In a further study, Quinn (1988a) used both the visuo-spatial and the verbal forms of the Brooks Matrix as his primary tasks. These two tasks were combined with either unseen incompatible arm movement or with brightness judgement. Concurrent movement substantially interfered with the visuo-spatial task suggesting the importance of movement in spatial coding. Brightness judgement also interfered with the spatial task but the impairment was much less substantial. This result is in contrast with the finding by Baddeley & Lieberman (1980) that brightness judgement had no effect on the Brooks spatial task. This result was interpreted by Quinn as being a general attentional effect acting through the CE. The verbal Brooks task was equally disrupted by both the movement and the brightness judgement tasks although to a limited extent. This unexpected result of the verbal Brooks task being disrupted by both secondary tasks was again interpreted by Quinn as reflecting interference with the attentional activity of the CE implying that this Brooks task does depend, to some extent, on the CE.

In addition, Quinn demonstrated that these interference effects were confined to the active encoding stage rather than to the maintenance stage. Quinn suggested that during maintenance, the CE involvement is lessened, and whenever the dependency of the VSSP on the CE is reduced, interference will also be reduced. A further study by Quinn (1991) supported this result which will be explained when discussing the encoding vs maintenance debate.

Quinn (1988b, 1994) conducted further experiments to delineate the nature of spatial coding and the characteristics of the sort of movement that causes interference with spatial processing. Quinn indicated that the results by Quinn & Ralston led to the conclusion that movement per se, rather than attention, was responsible for the decrement in performance. However, he indicated that this conclusion should be treated cautiously. Since, the movement task used by Quinn & Ralston was always in the same predictable direction, interference may not be due to movement per se but to particular characteristics such as movement predictability and sequencing. Hence, Quinn investigated the consequences of both predictable and non-predictable movement for spatial processing. If interference is due to movement per se, then both sorts of movement should interfere.

Quinn, using the technique of passive movement to minimise the CE involvement, found that passive unpredictable movement caused no disruption to performance on the Brooks Matrix task. Unpredictable movement refers to the situation where subjects can not predict where their arm is moving to next. However, passive predictable movement did interfere with the Brooks Matrix. This indicates that when subjects do not plan or control the movement, they can effectively retain the Brooks Matrix task, but when subjects plan and/or execute the movement then interference with the encoding of the matrix task occurs.

From these results, Quinn attempted to put forward an explicit definition of spatial processing by indicating that movement interference occurs when movement is to a sequence of specified targets, and that this target sequence must be known to the subject in advance. If these two conditions are met, then interference occurs even if the movement is passive and thus not initiated by the subject. In a further experiment, Quinn showed that the predictable and unpredictable passive movement tasks interfered equally, not selectively, with performance of the verbal form of the Brooks task. Theoretically, these two movement tasks should not have interfered with verbal WM and Quinn considered this as a general (CE) disruptive effect.

Working memory for movements was also investigated by Smyth and her colleagues in a series of experiments in which they contrasted memory for configured bodily movements to memory for movements to spatial targets. Smyth, Pearson, & Pendleton (1988), as their movement span task, required their subjects to remember a sequence of configured bodily movements. As their verbal span task, subjects were required to remember, in the same order, a series of visually presented words. Articulatory suppression was shown to disrupt both memory spans but when subjects were familiarised with the TBR movement, articulatory suppression had no effect on the movement span task. However, a configurational movement suppression task, involving touching various parts of the body, was shown to disrupt movement, but not verbal, span.

Smyth et al also used a spatial memory span task, the Corsi blocks, which involves remembering a sequence of locations or blocks arranged on a board. This spatial span task was found to be disrupted by the spatial tapping (suppression) task used previously by Farmer et al (1986) which involves tapping round four metal plates. However, the spatial span task was not disrupted by the configurational movements suppression task. On the other hand, memory span for configured bodily movements was found to be disrupted by the configurational movement suppression task but not by the spatial suppression task. Hence, indicating a double dissociation between WM for configured bodily movements and WM for movement to spatial positions. Such a dissociation was further supported by a study by Smyth & Pendleton (1989) in which they contrasted spatial memory span with memory for series of hand configurations. Spatial span was impaired by spatial tapping but not by repeatedly clenching and unclenching the hand. The opposite pattern of interference occurred for memory for configurational movement.

Such results support the notion that the VSSP is linked to the planning and control of movement to targets in space and that movement per se can not be important for the VSSP. Smyth & Pendleton indicated that movement which is implicated in the functioning of the VSSP is chiefly spatial in character and that the VSSP itself may derive from the need to maintain locations in external space in order to direct action towards them. This spatial movement is differentiated from patterned or configurational movement such as that involved in the ability to watch another person move and to reproduce that movement with one's own body. They argued that this ability may be a by-product of a movement system that has a different purpose from that of the VSSP, or it may exist in order to allow us to imitate. They also suggested that it may be necessary to add a third WM subsystem to those that have been investigated following Baddeley & Hitch (1974). This third subsystem would be involved in reproducing the configurational aspects of bodily movements.

In a further study, Smyth & Pendleton (1990) examined maintenance of these two sorts of movement in WM and argued for the existence of independent rehearsal mechanisms one for spatial sequencing and the other for configured or patterned movement.

<u>Encoding vs Maintenance:</u>

From the above review, it is clear that there is a growing literature on visuo-spatial processing as studied during encoding and retrieval of information. In contrast, maintenance of visuo-spatial information in the VSSP has not been widely studied and it has been indicated (e.g. Logie & Marchetti, 1991; Logie, 1995) that there is little literature investigating the means by which visuo-spatial information is maintained in STM. A basic question to be answered is whether the contents of the VSSP are susceptible to movement interference during encoding as opposed to maintenance or are they equally susceptible to interference during both encoding and maintenance. The following section will be devoted to examining studies that have attempted to examine this issue within the WM framework.

Few studies have examined the effects of movement interference during both encoding and maintenance of information in the VSSP (Idzikowski et al, 1983; Morris, 1987; and Quinn, 1988a, 1991).

Idzikowski et al required their subjects to follow a bell shape moving in a sinusoidal pattern on a stationary background screen while being presented with the sentences of the Brooks task. Subjects had to be ready to react whenever the bell shape changed. The study included conditions where both the bell and the background being stationary, both the bell and the background moving, and the background but not the bell moving. Results showed that only the conditions which involved eye movement caused interference with the recall of the spatial sentences whilst having no effect on the recall of the control sentences. In a further experiment, it was shown that interference occurred when eye movements were required during presentation or recall of the spatial sentences. Since these results did not differ from a condition in which eye movements were required throughout the experiment, it was concluded that the locus of the interference was most likely with the processes involved in the maintenance of the image. However, as pointed out by Quinn (1991), since interference with maintenance of the spatial sentences was never exclusively tested, such a conclusion may be unsafe.

Morris (1987) has shown that when memory for a pattern of different sized circles is coupled with concurrent nonvisual Moar box tracking, there is a mutual disruption of performance. This disruption occurred only if the secondary movement task was performed during the encoding of the pattern of circles, rather than during a retention interval. Articulatory suppression had no effect at encoding or maintenance. Morris also showed that the Moar box tracking task requires heavy CE resources since it also impaired memory for auditorly presented consonants. Morris concluded that CE resources are required to operate the VSSP in most circumstances except during maintenance rehearsal.

Morris's primary task involved memory for the random location of five circles on an otherwise blank screen with a capacity for up to 81 circles. The circles were serially presented and only one appeared on the screen at any one time. A criticism of Morris's study pointed out by Smyth & Scholey (1994a) was that the primary task used involved subjects having to recall the exact location of each of 5 circles, not the presence of items of known locations. Recalling the exact location of an item in an array with no identifiable structure may not require rehearsal, or the encoding task may be so difficult that the small number of items encoded can be maintained even with other secondary tasks. In other studies, Smyth & Scholey point out, the tasks that do show interference have easily identifiable stimuli, of which five or six can be recalled, and do involve order (e.g. Smyth & Pendleton, 1990; Logie & Marchetti, 1991). Such studies will be discussed shortly.

Quinn (1988a) investigated the effects of a spatial interference task on the Brooks spatial and non-spatial sentences at both encoding and maintenance. The spatial secondary task used was the spatial movement task used by Morris (1987), i.e. the Moar Box. Unlike Morris, Quinn included both the delayed and the concurrent interference conditions in the same experiment. Results were consistent with the findings reported by both Idzikowski et al and Morris. There was an interaction between timing of interference and sentence type. Recall of the spatial sentences was better under delayed interference in comparison to concurrent interference whereas the opposite pattern occurred for the control non-spatial sentences. These results also appear to isolate the encoding stage as the locus of the interference.

Quinn (1991) indicated that the above three studies, which tended to isolate the encoding stage as the locus of the interference, appear to contain a confounding factor. The interfering tasks used are effortful and thus may have placed a heavy load on the CE. Quinn indicates that whilst Idzikowski et al acknowledge the confounding and Quinn offers an explanation implicating the CE, Morris indicates the disruption of attention as the most obvious explanation and does so without the benefit of a control condition. Hence, Quinn attempted to clarify this issue by using the technique of passive incompatible arm movement to minimise the CE involvement. Quinn, using the Brooks spatial and control sentences as the primary tasks, tested the hypothesis that interference in the VSSP by a spatial movement task is confined to the active encoding stage rather than to the processes involved in maintenance. Results showed that interference was limited to the active encoding stage of the Brooks spatial sentences. There was no effect during maintenance of the information. The control sentences were marginally, but not significantly, affected by movement. Quinn suggested that one interpretation for such a result was the possibility that once formed, the Brooks directions are remembered as an overall static pattern rather than a sequence of discrete relative directions and are, therefore, not susceptible to interference by discrete movement. Another alternative explanation provided by Quinn is that maintenance involves a more conceptual long-term storage that demands an interplay of both spatial and semantic features. Such a complex representation would be much less susceptible to an interference paradigm although the complexity itself may have tractable memorial consequences.

Logie & Marchetti (1991) attempted to provide an interpretation for the results obtained by Morris (1987) and Quinn (1991) in which the encoding stage alone was isolated as the locus of movement interference. It is indicated that these results suggest that whatever cognitive systems are involved in encoding, are also involved in the control of active movement. Furthermore, these results suggest that the system responsible for retaining the information, once encoded, is most likely not associated with movement control. Such findings would contradict an assumption of the WM model which indicates the VSSP as being involved in retention of visuo-spatial information on a temporary basis. Moreover, the memory tasks used by Quinn and Morris (the Brooks Matrix & memory for locations of circles) do appear to require visuo-spatial processing and storage. One possible interpretation, Logie & Marchetti point out, is that the encoding of such primary tasks heavily involves the CE, that movement control also requires the CE, and that the disruption observed is a general distraction effect rather than reflecting competition for a specialised VSSP. Logie & Marchetti proposed a possible approach for studying the role of the VSSP and whether it is involved in retention rather than encoding.

This approach assumes two separate specialised systems, one spatial and one visual, and both operating more or less independently of a CE. Such a distinction would, at first blush, have some difficulty with the findings reported by Quinn and Morris since if there is indeed a subsystem specialised for dealing with spatial material, should not this subsystem be also involved in maintenance of spatial material. In other words, secondary movement should interfere with both encoding and maintenance if the same system is involved in each process. Logie & Marchetti argue in this regard that in the primary tasks used by both Morris and Quinn, only the initial encoding of the information needs to be a spatial process. Once encoded, such tasks, as the Brooks Matrix, are retained as only a static pattern of items in a passive visual WM system. The material of these tasks do not have to be retained as a sequence of imagined movements. This imagined pattern can then be used as a mnemonic for later recall. Retrieval may also be spatial assuming that subjects scan the retained image in order to report the digits. Hence, a spatial process may be involved during encoding and retrieval of verbal instructions that describe spatial positions as in the Brooks Matrix, whereas a passive visual store could be responsible for retention of the imaged pattern of digits in certain locations within a matrix. Logie & Marchetti suggest that genuinely requiring subjects to retain a sequence of movements rather than a static pattern, would make them rely on a spatial WM resource, and thus a secondary spatial movement task would interfere with such maintenance.

Logie & Marchetti have shown that when subjects are required to retain, for about ten seconds, a sequence of movements on the screen, their ability to do so was impaired by making unseen hand movements to spatial targets during the retention interval. Logie & Marchetti used a primary task which they claim to involve the subject retaining a sequence of movements instead of retaining a static pattern. Their task involved presenting six squares respectively in six different locations on a computer screen at the rate of one per second until all six squares were present on the screen. One second later, the screen became blank for 10 seconds after which the six squares reappeared in sequence. On half of the trials, the sequence in which the squares was presented was identical to that shown prior to the retention interval. On the other half, the order in which two of the squares appeared was changed. The task was then to indicate verbally whether or not the two sequences were identical. As indicated above, Logie & Marchetti reported that maintenance of such sequences was disrupted by a spatial movement task whilst a visual secondary task, irrelevant pictures, had no significant effect. The opposite pattern of interference occurred for a purely visual primary task, colour hues. Logie & Marchetti interpreted these results in terms of Logie's (1989) suggestion that the VSSP comprises two functions: a passive visual store and an active rehearsal process. The active rehearsal process is related to the control of movement and to some form of mental scanning of the visual representation. Retention of the visual primary task is accomplished by the passive visual store whereas retention of a series of movements (as in their primary task) would be accomplished by the rehearsal mechanism. Since the rehearsal mechanism is also involved in movement control, generating a series of irrelevant spatial movements would disrupt this mechanism resulting in poorer recall of the primary movement sequence.

In addition to the above studies, other studies using different paradigms, have reported interference with maintenance of visuo-spatial information. Smyth & Pendleton (1990) found that subjects' recall of six Corsi blocks positions in order was decreased when they watched someone else move to spatial targets during a retention interval. The effect was, however, restricted to order rather than item memory. A similar result was reported by Smyth & Pelky (1992) who showed that recall of a subspan set of spatial locations (Corsi blocks) was disrupted by a spatial tapping task during a retention interval. Counting backwards in threes also disrupted retention. Moreover, requiring subjects to engage in spatial tapping during encoding did not lead to additional decrement than if spatial tapping was performed only during maintenance, contrary to the results by Morris (1987). Counting backwards during encoding did lead to additional impairment. Since both spatial tapping and counting backward interfered, Smyth & Pelky suggested that the effects are unlikely to be purely spatial in nature, proposing that in spatial tasks in which order is maintained, demands are also made upon place-keeping functions which are not specific to the spatial system.

Smyth & Scholey (1994a) indicated that in the above studies that show interference during maintenance, the reason for that interference is not clear. The secondary tasks involve spatial attention shifts, movement to spatial targets, memory for sequences, and serial output, and any or all of these could be responsible for the interference with performance. Smyth & Scholey examined an alternative account to the suggestion (e.g. Baddeley, 1986) that maintenance of information in visuo-spatial WM involves implicit motor processes that are analogous to the AL in verbal WM. They proposed that such maintenance is based on shifts of spatial attention and examined the general hypothesis that if maintenance of a sequence of spatial locations involves attention shifts rather than implicit movements, then interference should be found whether subjects actually move or not. However, as movement to targets makes extra attentional demands, this movement should lead to further interference. Results indicated that recall of spatial memory span items was impaired by various tasks that were carried out during a retention interval. These tasks included seeing visual targets, hearing tones that come from one of two different directions, making categorical response to these tones, and making spatial movements.

Smyth & Scholey interpreted these results within a framework in which active spatial attention is involved in maintaining spatial items in order in WM, and is interfered with by any task (visual, auditory, perceptual, motor) that also imposes demands on spatial attention. Interference with spatial WM is therefore neither simply visuo-spatial nor spatial-motor, but accumulates over all sources of demands on spatial attention. Interference occurs because of active engagement with spatial targets, whether in the external environment or in memory. These findings thus suggest that maintenance of visuo-spatial information is active and is similar in some ways to active looking. This, Smyth & Scholey pointed out, suggests a strong analogy between visuo-spatial STM and the maintenance of visual images particularly in relation to the suggestion of Farah (1989) who proposed that visual imagery is like visual attention, and the proposal by Kosslyn (1991) and Kosslyn, Flynn, Amsterdam & Wang (1990) who suggested that maintaining a visual image requires effort. According to Smyth & Scholey such an analogy would be less successful for verbal WM and auditory images and should also be treated with caution in the visuo-spatial domain especially since the task used in Smyth & Scholey's study is closer to spatial imagery tasks than it is to visual imagery tasks and may not be related to the maintenance of form and colour. Annett (1995) indicated that these findings by Smyth & Scholey would reinforce the idea that the source of interference lies in the over-writing of a representation of space rather than in the generation of voluntary action. It would appear that movement as such is secondary to attending selectively to spatial targets which precedes the movement itself and is essential to the execution of an accurate motor plan.

2.7.4. Movement or the CE

From the above review of the studies that examined the role of movement in the VSSP, it is clear that there remains a debate regarding whether movement interferes with concurrent visuo-spatial processing because both tasks share a common visuo-spatial resource or whether interference is caused by CE involvement. A number of tasks have been used that appear to involve processing and storage of visuo-spatial information in STM. Examples of these tasks are: visualising number-matrix patterns, (e.g. Brooks, 1967; Baddeley & Lieberman, 1980); remembering abstract and irregular patterns (Broadbent & Broadbent, 1981); the use of visual imagery mnemonics (e.g. Logie, 1986); and random square matrices (Phillips & Christie 1977a&b). However, as indicated by Logie et al (1990), the nature of the short-term processing and storage function involved in these tasks has been a topic of some considerable debate. In general, one debate is related to the issue of whether the interpolated tasks used with these primary tasks were affecting overall capacity rather than just the functioning of a specialised visuo-spatial or motoric store.

The Brooks Matrix task has been the most widely used task and various movement tasks have been shown to interfere with encoding of this task (e.g. Baddeley et al, 1975b; Baddeley & Lieberman, 1980; Quinn, 1988a). However, a major criticism of these studies and other studies using different paradigms (e.g. Farmer et al, 1986; Morris, 1987) is that they have arguably confounded their interpretation by failing to control CE effects (Quinn, 1990, 1991, 1994). The following section will attempt to shed more light on the Brooks Matrix task and the assumptions and problems associated with its processing.

Problems with the Brooks Matrix task:

The Brooks Matrix task, which was explained at the outset of this chapter (see Figure 2.1), has been extensively used in the WM literature and has been the most frequently used task to investigate the characteristics of the VSSP in general and the role of movement in particular (e.g. Baddeley et al, 1975b; Baddeley & Lieberman, 1980; Idzikowski et al, 1983; Quinn & Ralston, 1986; Quinn, 1988a&b, 1991, 1994). Quinn & Ralston (1986) indicated that techniques used to investigate the VSSP are often derived from Brooks (1967,1968) whose tasks are assumed to involve the VSSP. The Brooks Matrix task (Brooks, 1967), in its two forms, has been very instrumental in establishing a dissociation between the two subsystems of WM, the AL and the VSSP. Lately, the visuo-spatial form of the Brooks task has been used frequently in visuo-spatial WM experiments to investigate movement and spatial processes in WM and to attempt to examine a possible dissociation between motoric and visual WM.

As indicated in the above review of the literature on the VSSP, the Brooks Matrix task has been frequently used as a primary visuo-spatial task in studies that sought to demonstrate the existence of an independent visuo-spatial or motoric component within WM by showing that concurrent movement selectively disrupts performance on the Brooks matrix spatial task, but not performance on its control verbal form. Such studies also sought to investigate the nature and characteristics of this system and the role movement might play in visuo-spatial coding. Various secondary visuo-spatial tasks have been shown to interfere with this task, with interference being confined to active encoding, and possibly retrieval, rather than maintenance. These secondary tasks included, Laffayette pursuit rotor tracking and nonvisual auditory tracking (Baddeley et al, 1975b; Baddeley & Lieberman, 1980); Moar box tracking (Quinn, 1988a); active and passive incompatible arm movement (Quinn & Ralston, 1986; Quinn, 1988b, 1991, 1994), intentional eye movement (Idzikowski et al, 1983) and spatial tapping (Salway, 1990). However, most of these secondary tasks, except passive arm movement, have been indicated (Quinn, 1990, 1991) to be effortful and are likely to have involved the CE, and it is unclear to what extent these tasks themselves caused interference or whether the interference was caused by the attention to the tasks. In fact, Morris (1987) demonstrated that the Moar box tracking task makes heavy demand on the CE. Moreover, studies that attempted to examine the visual vs spatial nature of the VSSP, used interference tasks that appear not to be entirely comparable in all respects except the one aspect that should be varied. For instance, a 'spatial' task such as the Moar box has been compared to a 'visual' task of making brightness judgement.

In addition to these difficulties with the secondary tasks, the Brooks Matrix task itself has been indicated to be inherently difficult task. For instance, Logie et al (1989) and Logie et al (1990) argued that there is a substantial general processing load involved in performing the Brooks Matrix tasks, in addition to their specialised processing requirements. In addition to this indication by Logie et al (1989, 1990), the involvement of the CE in the performance of the Brooks Matrix task, particularly at encoding, has been suggested by numerous researchers and studies in the literature. For instance, Morris (1986a) pointed out that a major problem with the early Baddeley experiments was that all the tasks used, including the Brooks Matrix, have a large verbal component. The spatial tasks used require initial verbal encoding with transformation into spatial representations. This implies that the stimuli must first be represented in the central processor with subsequent rapid registration onto the SketchPad. More recently, Wang & Bellugi (1994) indicated that a variety of tasks has been employed for the assessment of the VSSP. Many of these tasks, including of course the Brooks Matrix task, incorporate the confounding task of constructing a mental image from verbal input. Quinn (1988a) found that the matrix task is susceptible to movement interference during encoding and retrieval, but not during maintenance. Quinn indicated that during maintenance of the Brooks task, the dependency of the VSSP on the CE is lessened. Whenever the dependency of the VSSP on the CE is reduced, interference will also be reduced. Salway (1990, 1991) concluded that the spatial encoding of the Brooks Matrix task involves a very high CE involvement. Finally, Logie & Marchetti (1991) indicated that "the CE is involved in encoding the Brooks Matrix material in some form of mental image, but is less important for maintenance of the information in that image, or the image itself" (p.113). These studies also point out a possible CE involvement during retrieval of the Brooks visuo-spatial matrix task.

Very recently, Logie (1995) discussed the findings by Quinn (1988a, 1991) that concurrent movement and brightness judgement secondary tasks interfered with the Brooks Matrix task, that both these secondary tasks also had disruptive but small effects on the verbal form of the Brooks task, and that the disruptive effects on either of the Brooks tasks are confined to active encoding rather than maintenance. Logie indicated that these results point to some general processing load involved in combining these kinds of tasks. The fact that any disruption occurs only during encoding, might suggest that data from the dual task studies involving the Brooks tasks could be interpreted in terms of some general processing function. Logie pointed out that evidence in the literature suggests that there remains considerable uncertainty as to whether performance of the Brooks visuo-spatial task relies primarily on a specialised visuo-spatial resource or on CE resources. There is also uncertainty regarding which aspect of functional cognition would be involved in initial encoding of the matrix material, in maintaining the material, and in retrieving the material. Since Quinn's data suggest that a general processing load may be crucial, it would be useful, Logie argues, to provide a more direct test of how much of a general load is involved in the Brooks tasks given their central role in the development of the VSSP.

Salway (1990, 1991) attempted to directly test the general processing load associated with performance on the Brooks Matrix tasks. Salway equated levels of control performance on the Brooks spatial task and its verbal version. The interference effects of three concurrent tasks on performance were then examined. Articulatory suppression caused more disruption to the nonsense verbal task than to the visuo-spatial task. Spatial tapping (Farmer et al, 1986) brought about the converse effect. This result supports the view that the matrix task relies on the

VSSP whereas its verbal control relies on the AL. However, a presumably CE task, random generation (Baddeley, 1966c) caused a much larger impairment on both Brooks tasks, and this impairment was even significantly greater for the visuo-spatial matrix task. The matrix task places greater demands on the CE than does its verbal version. This led Salway to conclude that the Brooks Matrix task requires a greater input from the CE component and may therefore involve more general processing load (be more 'difficult') than its verbal equivalent.

Logie (1995) suggested that these results by Salway, along with Quinn's data, indicate that the Brooks Matrix task relies heavily on CE resources, at least during encoding, and therefore can not be taken as clear evidence for the use of a specialised visuo-spatial WM resource, and that it is "unwise to rely too heavily on data derived from the Brooks tasks"(p.86).

From the above discussion of the role of movement, it is clear that various movement tasks have been found to interfere with concurrent visuo-spatial processing. It is not clear, however, whether concurrent movement interferes with the visuo-spatial representation as such, or with other processes involved. The most widely used visuo-spatial primary task, the Brooks Matrix, appears to be an inherently difficult and complicated task that involves various codes and processes. Evidence for this difficulty of the Brooks task was discussed above.

2.8. Concluding remarks and the research problem

The aim of this experimental study is to explore the nature of the VSSP subsystem of WM, and specifically to examine the role of movement in visuo-spatial WM. Concurrent Movement has been indicated by numerous studies to interfere with visuo-spatial information believed to be held in the VSSP with interference mostly shown during encoding and retrieval rather than during image maintenance (e.g. Baddeley et al, 1975b; Baddeley & Lieberman, 1980; Quinn & Ralston, 1986; Farmer et al, 1986; Morris, 1987; Quinn 1988a, 1991). The basic research question is why movement should be so disruptive; Is it because both the primary and the secondary tasks require a common resource within WM? If so, what is the nature of that resource? Is it a representation of space or is it perhaps the involvement of the hypothetical CE? The concept of the CE has been indicated to be elusive and evidence for the role of this supervisory system of WM is scant and there is a problem in attempting to separate its effects from those of its subordinates (e.g. Baddeley, 1993; Logie & Salway, 1990; Logie et al, 1990; Morris & Jones, 1990; Quinn, 1990, 1991). For instance, it is far from clear whether concurrent movement interferes with visuo-spatial processing because they share a common WM resource (VSSP), or whether the interference is caused by switching attention to the tasks.

This study attempted to approach this prominent and controversial issue via the Brooks Matrix task which has been widely used as a vehicle for studies of the VSSP, especially for those (e.g. Baddeley, Quinn) which have demonstrated movement interference effects. As this task is also acknowledged to be a complex task, a first aim of this study was to attempt to examine the cognitive processes and codes involved in performance of this task, particularly the involvement of the CE. As such, this attempt will form another attempt, besides that of Salway (1991), at directly testing the general processing load associated with performance of the Brooks Matrix task, although in a quite different way as will become clear throughout this thesis. As indicated in the previous section, the need for such an attempt has very recently been reiterated by Logie (1995).

2.9. An outline of the empirical work

The overall objective of this research programme is to examine the role of movement in the VSSP using a movement interference paradigm. The following four chapters present a series of experiments which investigated the effects of various movement tasks on performance of some new variants of the Brooks Matrix task. A process model of the Brooks Matrix task is presented which combines features of the WM model and Annett's ALI model. This process model is explored through a series of experiments systematically varying presentation and recall modes and the nature of the secondary movement tasks.

The next chapter presents Experiment (I) which attempted to examine the cognitive processes involved in performance of the Brooks Matrix task. Two issues were examined. The first was the effect of replacing the use of the digits 1-8 by using images/pictures of simple and easily imageable objects. The second issue examined was the effect of systematically varying the encoding and decoding methods between verbal and visual modalities. This manipulation resulted in four input-output combinations or experiments. The overall aim was to examine the processes involved in processing this task and thus attempt to devise a proper visuo-spatial variant that may enable examining some hypotheses regarding the role of movement. Results of these four experiments are then discussed.

Chapter 4 presents an attempt to account for the results of Experiment (I). A process model of the Brooks Matrix is proposed. This model attributes the difficulty associated with verbally encoding the task to the heavy CE involvement to switch attention between the external input (the sentences) and the internal input (image generation from LTM). With visual presentation, no image generation is needed since the task materials are assumed to be directly encoded onto the visual buffer. Thus the CE is assigned a specific role in image generation. The process model was examined by Experiment II using a movement interference paradigm. The effects of various secondary movement tasks on the verbal and visual encoding of the Brooks Matrix task were examined. A hypothesis was tested by each secondary task.

In chapter 5, it is argued that the task is still not a pure visuo-spatial task. A more simplified variant of the task is suggested and examined by Experiment III. In this new variant, the use of the digits and the sentences was dispensed with and the pattern TBR was presented merely as a series of spatial directions. In addition, a more direct method of visual recall was used which involved the subject simply drawing a line representing their mental image on a real matrix. This simplified variant was examined by systematically varying the methods of encoding and decoding between verbal and visual modalities which resulted in four input-output combinations or conditions.

Chapter 6 presents Experiment IV which used the simplified visually presented and recalled variant to test some hypotheses regarding movement interference with maintenance of visuo-spatial information. In particular, this last experiment attempted to test the proposal of a rehearsal or a refresh mechanism for the VSSP comprising an 'inner scribe' rewriting material to an 'inner eye' (Reisberg & Logie, 1993).

Chapter 7 provides a summary and a discussion of the overall results of this study. The implications of these results to the nature and characteristics of the VSSP and to the relationship between imagery and WM in general are discussed.

2.10. Imagery Questionnaires:

In Experiments II, III and IV, subjects were asked to answer the Vividness of Movement Imagery Questionnaire (VMIQ) or the Vividness of Visual Imagery Questionnaire (VVIQ) prior to testing. The purpose was to examine whether there was a correlation between vividness of movement or visual imagery and performance on visuo-spatial memory tasks such as the Brooks Matrix task (or some new variants on this task). The VMIQ was developed by Isaac, Marks & Russell (1986) for the purpose of identifying individual differences in the visual imagery of movement and imagery of kinesthetic sensations associated with movement. Isaac et al reported a test-retest reliability coefficient of 0.76 which was taken as suggesting that the VMIQ is a reliable instrument concerning the visual imagery of movement. The questionnaire (see Appendix 1.1) is composed of 24 items relevant to movement imagery: visual imagery of movement itself and imagery of kinaesthetic sensation. The items fall into 6 groups of 4 items each. The 6 groups contain items relating to: basic body movements, basic movement with more precision, movement with control but some unplanned risk, movement controlling an object, movements which cause imbalance and recovery, and movements demanding control in aerial situations. The items relate to common situations and not to specific motor skills. Each item requires the subject to imagine making a specified movement such as jumping into water. Subjects are required first to imagine someone else performing the action (external or third person perspective) and then to imagine themselves performing the same action (internal or first person perspective). Subjects rate the vividness of each image on a 5-point scale.

The VVIQ, on the other hand, was developed by Marks (1973a) and consists only of visual items to meet the need, indicated by Marks, to assess imagery in a specific modality and thus the need for a more specific measure of visual imagery than that available from the questionnaires of the multi-modal approach such as the Questionnaire upon Mental Imagery (QMI). The QMI, developed by Betts (1909), is considered to be the most widely used instrument for assessing imagery ability. It consists of 150 items associated with the vividness of evoked imagery in seven modalities: visual, auditory, cutaneous, kinesthetic, olfactory, gustatory, and organic. The QMI was shortened by Sheehan (1967) to include only 5 items in each of the seven modalities. Marks (1973a) and Isaac et al (1986) argued that the QMI lacks validity when applied to investigations of performance based upon a specific sensory modality or category of response and they indicated the need to use the single modality approach when assessing various imagery abilities.

The VVIQ (see Appendix 1.2) contains 16 visual items: 5 visual items borrowed from the original QMI and 11 new items constructed by Marks. The items refer to common situations and scenes and the subject's task is to rate the vividness of the visual imagery that the items evoke. One unique feature of the VVIQ is that each item is rated twice, once with the eyes open and once with the eyes closed. A total score is obtained by adding the two ratings for all the 16 items. The rationale underlying this procedure of rating each item twice is unclear and work regarding the psychometric properties of the VVIQ has shown that there is no difference between the two ratings (e.g. White, Sheehan & Ashton, 1977). Each item is rated along a 5-point scale of vividness which was obtained by dropping two response categories from the 7-point scale of the QMI. Marks adapted the 5-point rating scale from the original 7-point scale of the QMI which he regarded as inappropriate since it demands too fine discrimination within the range defined by the two extreme values. The 5-point scale contains two extreme values, a mid-point, and only one extra scale-value on each side of the mid-point. Marks (1972) reported that the VVIQ has a test-retest reliability coefficient of r=0.74 and Isaac et al (1986) reported a similar test-retest reliability of r= 0.75. A split half reliability coefficient of 0.85 was reported by Marks (1973a). Marks (1972) argues that the VVIQ is a valid discriminator of subjects with poor and good visualising ability. Although rivalled in popularity by Sheehan's (1967) revised version of the QMI, the VVIQ has been employed in over 100 empirical studies (Marks, 1989a).

Chapter 3

Examining the cognitive processes involved in performance of the Brooks Matrix Task.

The review of the literature in chapter 2 has shown that progress in investigating the VSSP has recently generated a number of debates regarding its characteristics. One considerable debate is regarding the role of movement in the VSSP and whether movement interferes with concurrent visuo-spatial processing because both tasks share a common visuo-spatial resource or whether interference is due to the involvement of the hypothetical CE. Movement interference is more marked during encoding and retrieval than during image maintenance (e.g. Morris, 1987; Quinn, 1988a, 1991). Most of the interference tasks have been indicated as being difficult and effortful. For instance, Quinn (1990, 1991) argued that a major problem with studies that show movement interference with the VSSP is that such studies contain a confounding factor. The interference tasks used are effortful and are likely to have involved the CE. It is, Quinn argues, unclear to what extent these tasks themselves cause interference or whether the interference is caused by the attention to the tasks. Many experiments showing interference effects have arguably confounded their interpretation by failing to control the CE effects. Quinn concluded that any experiments which have as their goal a more precise delineation of interference effects in the VSSP must attempt to minimise the contribution of attention.

In addition to these problems with interference tasks, the review of the literature has revealed that the most frequently used visuo-spatial primary task, the Brooks Matrix, is an inherently difficult task that appears to involve various codes and processes in addition to its visuo-spatial component. It is not clear whether concurrent movement interferes with the visuo-spatial representation or with the other processes involved. Evidence from various sources for the complexity of the Brooks Matrix task was presented in chapter 2. Furthermore, it has been pointed out (e.g. Logie, 1986; Logie & Baddeley, 1990) that progress with the VSSP has been slower than that with the AL largely due to a lack of effective techniques for its investigation. A variety of presumably visuo-spatial memory tasks have been used but the nature of the short-term processing and storage function involved in these tasks has been a topic of some considerable debate (Logie et al, 1990). It is not clear whether the interpolated tasks used with these primary tasks are affecting overall capacity rather than the functioning of a specialised visuo-spatial store. Therefore, there is an obvious need to use both primary and secondary visuo-spatial tasks that make minimum demands on the CE in order to be able to conclude that a secondary movement task interferes with a primary visuo-spatial task because both utilise a common spatial or 'motoric' resource in WM.

Hence, the purpose of this experiment was to examine the cognitive processes involved in performance of the Brooks Matrix task. The 'nonsense' verbal version of this task was not used in this study. The long-term aim was to attempt to develop a simplified variant of this task that will enable testing some hypotheses regarding movement interference during encoding and maintenance rehearsal of visuo-spatial material. Some questions to be answered include, does movement interfere with visuo-spatial processing because both tasks share a common WM resource? Is this resource a representation of space or is it perhaps the involvement of the CE? If movement does interfere, then what sort of movement, and is the VSSP spatial in nature or does it also have a purely visual component? That is, is there a separate spatial WM store that mainly deals with dynamic information pertaining to location and movements in space, as opposed to a visual store that mainly deals with static pictorial information pertaining to identity and other visual characteristics of objects and patterns in space? Within the WM literature, there is a controversy over whether mental images are either visual or spatial representations or rather that imagistic representation, like perceptual representation, consists of both visual and spatial representations. Moreover, if movement does interfere then at what phase does interference occur (encoding, maintenance, or retrieval) and does maintenance of visuo-spatial information and images involve a rehearsal loop comprising an *inner scribe* rewriting material to an *inner eye* as proposed by Reisberg & Logie (1993; see chapter 2)? Baddeley (1992a) indicated that it is still not clear what process underlies the active rehearsal of visual imagery, playing the spatial equivalent to the role of subvocalisation in the AL. Eye movement and the system involved in its control has been implicated in the process of rehearsal of images but with no sufficient evidence.

In investigating the cognitive processes involved in performance of the Brooks Matrix two issues were examined. The first was the effect of replacing the digits 1-8 in the standard Brooks (SB) task (see Figure 2.1) with a set of visually distinctive, readily imageable objects. Coloured pictures of 8 simple objects such as a duck, a train, were substituted for the digits in the SB task. This modified version is referred to as the Picture Brooks (PB) task. The purpose of using these objects was to test whether their pictorial quality and ease of imaging would bring about improvement in performance relative to performance on the SB. If a specialised visuo-spatial WM store is primarily involved in encoding and processing the Brooks Matrix, then using visually distinctive, easily imageable items might enhance recall.

The second issue explored was the encoding and decoding processes. The methods of presentation and recall of both the SB and PB versions were varied between verbal and visual modalities. Verbal presentation refers to aurally presenting the sentences that describe the locations of the 8 digits (objects) within the squares of the matrix. Verbal recall refers to requiring subjects to repeat verbatim the sentences using their mental image to help reconstruct the sentences as in the original Brooks procedure (see chapter 2). During these verbal modalities no matrix was present at input or output. Visual presentation, on the other hand, refers to presenting the task material by a slide-projector with each slide showing one of the 8 digits (objects) in its designated square within an otherwise blank matrix. Visual recall refers to having subjects respond by arranging 8 cards, containing the digits or the pictures of objects, in their designated squares on a real matrix. This manipulation resulted in 4 different input-output combinations (experiments): Verbal-Verbal, Verbal-*Visual*, *Visual*-Verbal, and *Visual-Visual*.

3.1. Experiment 1-A

The effect of replacing the digits on the standard Brooks task with simple & easily imageable objects

3.1.1. Introduction:

The purpose of this preliminary experiment was to examine the suggested pictorial version of the Brooks Matrix task in which the digits 1-8 were replaced by familiar, easily imageable objects. Performance on this PB task was compared to performance on the SB task. It was predicted that, if the Brooks task is encoded and processed primarily by a specialised visual WM store, then using visually distinctive, easily imageable objects might lead to improvement in performance relative to performance on the SB task. This experiment was designed to provide some information regarding the suitability of this modified version of the task. It should enable issues to be examined such as whether the new material is acceptable to subjects and of appropriate difficulty, the optimal size of the matrix, how many items should be presented, and so forth.

The same procedures used in the original Brooks Matrix task were used here. Both the SB and the PB tasks were presented to subjects verbally. In both conditions, subjects were instructed to attempt to remember the sentences by forming a mental image of the digits (objects) relative to one another within a visualised matrix. They were informed that this mental image could then be used at recall to help in verbally reconstructing the sentences. Hence, both the SB and PB tasks were presented and recalled verbally. As such, this experiment represents the first input-output combination (verbal-verbal) resulting from the variation in the encoding and decoding methods between verbal and visual modalities.

3.1.2. Method

Material & Equipment:

As in the original Brooks Matrix task (Brooks, 1967; see chapter 2), a 4X4 square matrix was used with the second cell on the second row always marked as the starting square. Subjects were first shown this matrix. Then the matrix was taken away and subjects were asked to visualise this matrix before being presented with a sequence of 8 sentences describing a path around the squares of the imagined matrix. The path always began from the starting square and involved placing the consecutive digits 1-8 in their successively designated locations within the squares of the 'mental' matrix. The sequences always began from the same starting square and always dealt with the digits in ascending numerical order. The first sentence of each spatial message was always the same (In the starting square put a 1). The only way in which different messages (sequences of 8 sentences) differed was the sequence of transitions (up-down, right-left) from one square to another. These sequences were designed so that two different digits were never assigned to the same square and that a digit was never placed outside the matrix. For the purpose of this experiment, and subsequent experiments, 8 small cards (4.5x5.3cm) were made, each containing one of the digits 1-8. These cards were made by printing each digit on one card. This standard Brooks task is referred to in this experiment as the SB and is designated as condition 1.

In the pictorial variant of this matrix task, simple, readily imageable objects were used instead of the digits 1-8. The experimenter identified 8 objects that were assumed to be familiar and easily imageable to subjects. These were: Duck, Train, House, Ball, Car, Cup, Tree, & Bear and they were always presented in this order. Schematic or toy-like pictures of these objects were obtained from a child's matching game on 4.5 x 5.3cm cards (see Appendix 2.1). The size of these cards was the same as that of the cards containing the digits 1-8. This pictorial variant is referred to as the PB and is designated as condition 2.

With the exception of using objects instead of digits, there was no modification in the Brooks standard procedure. In each condition, 2 practice trials were given followed by 6 experimental trials. Therefore, 8 different spatial sequences of 8 sentences were needed for each condition. These sequences always started from the same square, and hence the first sentence of each sequence was always the same whilst the other 7 sentences described the locations of the digits (objects) in adjacent squares around the matrix. Each set of 8 sentences began with the sentence "In the starting square put a 1" with the following sentences having the form "In the next square up (down, to the left, or to the right) put a 2, and so on until the location of the last digit (object) is described. In no set of 8 sentences were the same "spatial directions" given more than two times in sequence. The experimenter constructed 8 sequences (tests) of 8 sentences for the SB condition. For the PB condition, these 8 sequences were used with one modification, the digits 1-8 were replaced by the names of the 8 objects in the same order stated above (see Appendix 2.2).

In both conditions, the two types of sequences were presented verbally at the rate of 1 sentence per 2.5 seconds as in the Brooks procedure. Generally, this rate is assumed to be sufficient for the spatial adjectives to be encoded using the matrix, but too rapid to allow subjects to perform the much more arbitrary recoding that would be required to remember the nonsense sequences spatially (Baddeley, 1986). The sequences of sentences were recorded, using a male voice, on an audiocassette and used with all subjects. A Birkbeck Timer metronome was used during recording in order to pace the rate of presentation at 1 sentence per 2.5 seconds. These sentences were thus played out to subjects from a tape-recorder during testing. Another tape-recorder was used to record subjects' responses.

Experimental set-up & Procedure:

Subjects were tested individually. The subject was seated at a rectangular table. The experimenter sat at the left end of the table which is located on the left hand side of the subject so as not to be facing the subject. In front of the experimenter, a 30cm-high x 45cm wide wooden stand was placed on the table. The stand was designed so as to have 16 small pockets for holding the 16 small cards that contain the digits or the pictures of objects. This stand also served another function which is to hide the other test material from the sight of the subject. The two tape-recorders were placed on the table, one for presenting the Brooks tests and the other for recording subjects' responses. A photograph illustrating the set-up is provided in Appendix 2.1.

The subject was initially introduced to the task. He (she) was shown a 4x4 square matrix, printed on an A4 paper, with the starting square marked with a cross. In the PB condition, each subject was familiarised with the 8 objects and shown their pictures, and in the SB condition the subject was shown the 8 cards that contain the 8 digits. The subject was informed that the digits (or objects) would always be in the same order and was in the PB condition required to memorise the order of the objects. Then the subject was told that he (she) was required to listen to a set of 8 sentences describing the locations of the 8 digits (objects) in relation to one another within the matrix. Subjects were told that the 8 sentences were of the sort *"In the starting square put a 1 (or a duck), In the next square up (down, to the left, or to the right) put a 2 (or a train), In the next square to the left (to the right, down, or up) put a 3 (or a house)"* and so on until the location of the last digit (object) was described. Subjects were shown how the sentences related to the matrix and were informed that the first digit (object) was always placed in the same starting square whilst the other digits (objects) were successively placed next to one another within the squares of the matrix. Also they were informed that during testing the matrix will not be present and that they are supposed to rely on forming an image of the digits (objects) on a path around the matrix. It was also explained that the only way in which tests differed was the sequence of spatial transitions (up, down, to the right, to the left) from one square to another.

The subject was instructed that the task was to repeat the 8 sentences word by word after the last sentence of each 'test' had been presented. Subjects were instructed to attempt to remember the sentences, that describe the locations of the digits (objects) relative to one another within the matrix, by forming a mental image of the digits (objects) in relation to one another within the matrix. They were told that this image could then be used to reconstruct the sentences at recall.

In the PB condition, it was noted from testing two pilot subjects that although the pictures of the 8 objects are visually distinctive, they lacked the intrinsic order of the digit series and so before testing proper, subjects were required to learn the sequence of the 8 objects and the same sequence was preserved throughout testing. The subject was required to memorise the 8 objects in the same above order using the method of serial-anticipation. This method (Reber, 1985) refers to a technique in verbal-learning where each stimulus in a list is a cue for a response to follow. The subject's task is to make the correct response before being prompted with it (the response must be made in anticipation). In the case of the 8 objects, each picture of each object acted as a cue for the next object. The experimenter ensured that the subject had memorised the order of the objects by testing them using this method of serial-anticipation. Three consecutive successful trials were considered a prerequisite criterion for commencing testing on this condition. No pictures of the objects were presented to subjects during practice or testing trials.

Thus, during testing the sequences of sentences were played out, from the tape-recorder, at the rate of 1 sentence per 2.5 seconds. Subjects' responses to the 6 testing trials were simultaneously hand-recorded by the experimenter on blank matrices by writing down each item in its relevant square as recalled by the subject. For this purpose, 6 small 4x4 matrices were produced on two different A4 sheets to be used for recording responses in the two conditions. Responses were also tape-recorded in order to double-check the accuracy of the experimenter's recording. As in the Brooks procedure, no limit was put on response time and subjects were not given specific knowledge of results but were periodically encouraged about their performance. A Specific set of instructions was prepared for each condition and used with all participants (see Appendix 2.3).

Subjects:

Fifteen participants (7 males & 8 females) were recruited from students attending undergraduate and postgraduate courses at Warwick University and took part in this experiment. Their age ranged from 19-36, and each was offered a fee of £2.

Experimental Design:

A within subjects repeated measures design (2 conditions x 6 trials) was used. After the initial introduction to the task, each subject was given 2 practice trials on the first condition on which he (she) was to be tested. Then, the subject was tested six times on that condition. Next, the subject was given 2 practice trials on the second condition and was then tested six times on that condition. The order of administering the two conditions was counterbalanced so that one subject was given the SB condition first and the next subject was given the PB condition first and so forth. Testing in both conditions was as follows:

Subjects were initially introduced to the task. After this introduction, the subject was given 2 practice trials on the current condition. During the first practice trial, the subject was presented with the 4x4 square matrix with the starting square marked and asked to listen to the first sequence (test) of 8 sentences and to repeat verbatim the sequence after all of the 8 sentences had been presented and the diagram was removed. Then a second practice trial was given, using the second test, without the matrix being present at encoding or decoding. In each condition, the first two tests of the relevant set of 8 tests were always used for the practice trials. After this practice period, each subject was tested 6 times on the current condition using the remaining 6 sequences. During this testing no diagram was present at input or output. After the subject had been given one condition, he (she) was then given the other condition using the same steps, starting with 2 practice trials and then being tested 6 times. In the PB condition, testing was preceded by a training period during which the subject memorised the order of the objects.

3.1.3. Results

A comparison between performance on both conditions was carried out. Errors were counted for each subject in each condition. An error refers to any sentence that was recalled incorrectly in terms of its spatial adjective or in terms of the identity of the digit (object) involved. In each trial, 8 sentences had to be recalled. The first sentence involved no spatial adjective and was always the same and thus involved no errors. There are therefore 7 possible errors in each trial and since each subject was given 6 experimental trials, there are 42 possible errors per subject in each condition. Table 3.a shows the mean percentage of errors made at each condition and Figure 3.1 illustrates these data. All analyses reported as significant in this and the subsequent experiments were significant at or beyond the .05 level.

Condition	Mean	N	SD
Standard Brooks	15.24	15	16.27
Picture Brooks	17.94	15	17.93

Table 3.a. Mean percentage of errors made at each condition.

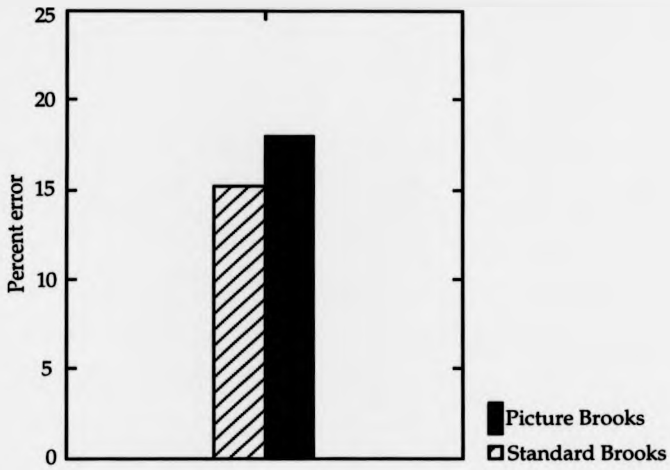


Figure 3.1 Mean percentage of errors made at each condition.

From figure 3.1, it appears that there is no large difference between performance on the SB and the PB conditions. A paired samples t-test was conducted on this data and showed no significant difference between the two conditions ($t=0.84$, $df=14$, $p=0.42$).

An analysis of the SP effect was conducted on the data in both conditions in order to find out whether subjects made more errors at the beginning or at the end of each set of 8 sentences (positions). Errors made at each of the 8 serial positions were counted in each condition. Fifteen subjects were tested and each was given 6 trials, thus each position had 90 chances of being error. Figure 3.2 shows the mean percentage of error made at each SP in both conditions.

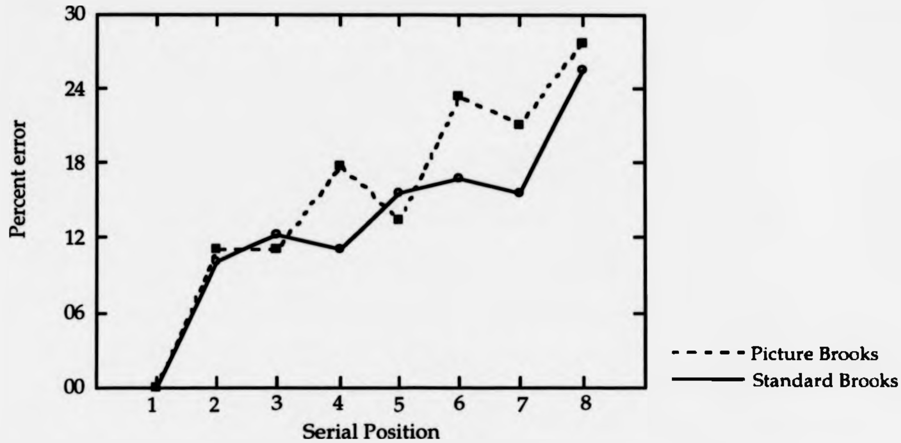


Figure 3.2. The serial position curves for both the SB & the PB conditions

The two curves shown in figure 3.2 do not appear to differ significantly with the error rate increasing approximately linearly with SP. No errors were made at position 1 since it is always the same sentence, in the starting square put a 1 (a Duck), which makes it almost impossible to make any error. Therefore, position 1 was excluded from the SP statistical analysis. A two-way ANOVA was performed on the data with task-type (SB vs PB) as the independent factor and serial positions 2-8 as the repeated measures variable. This analysis showed no significant main effect of task-type [$F(1,14)=0.71$, $P=0.42$]. Similar numbers of errors were made at the two conditions. There was a highly significant main effect of SP [$F(6,84)=5.75$, $P=0.00$]. In both conditions, significantly more errors were made at some positions than others. The interaction between task-type and SP was not significant [$F(6,84)= 0.86$, $P=0.53$]. The two curves do not differ significantly.

3.1.4. Discussion

Results of this preliminary experiment showed that the new variant of the Brooks Matrix is almost equivalent to the SB in terms of task difficulty. Subjects' performance on both tasks was not significantly different. Replacing the digits in the Brooks Matrix task by simple, readily imageable objects and showing their pictures to subjects makes no significant difference to performance on the task, provided that subjects are offered the chance to memorise the order of those objects. Using visually distinctive objects did not lead to improvement in performance but, on the contrary, it led to insignificantly more errors being made in the PB condition. Subjects indicated to the experimenter that they concentrated more on forming a spatial image of the objects (or digits) in relation to one another within the matrix rather than having images of the objects used. For instance, some subjects indicated that in recalling the items of the PB task, they mainly relied on forming and maintaining a spatial pattern of the objects rather than having vivid images of the objects in their relevant cells of the matrix. The fact that subjects made more errors at the last few sentences (positions) seems to be due to having difficulty in maintaining such a spatial image of the items in relation to one another within the matrix.

In regard to the SP effect, the analysis showed that subjects in both conditions made more errors at the end of each set of 8 sentences. Error rate seems to be at its lowest level when recalling the first few sentences, and then it increases approximately linearly with SP. This pattern indicates the presence of a primacy effect and a 'negative' recency effect. This lack of a recency effect could be due to the fact that this experiment is different from classical SP experiments which are free-recall experiments. In this experiment, the task was to recall the items in a serial order. The sentences were recalled in the same order in which they were presented. In general, the SP effect in verbal free-recall experiments refers to the generalisation that the likelihood of an individual item being recalled is a function of the location of that item in the serial presentation of the list during learning. Items which are toward the beginning of the list (primary) and those toward the end (most recent) are more likely to be correctly recalled than those in the middle. In this experiment, the most recent items had the highest error rates probably because the items were recalled in a specific order and specific spatial relations. Many subjects indicated that they relied on forming a mental pattern and that it was easier to recall the beginning of this pattern. This analysis of the SP effect was carried out on the assumption that it would provide some insight into various issues such as the strategy used by subjects in encoding and processing the task, and the capacity of the VSSP to maintain a number of items or locations. These issues will be discussed in subsequent sections of this thesis.

Thus far, it appears that for the Brooks Matrix task the kind of material used (digits or objects) doesn't make a significant difference and that the crucial element in performance seems to be the ability to encode and maintain a spatial image of the items and use this image as a mnemonic to reconstruct the sentences at recall. However, it should be noted that in this experiment, as in the Brooks procedure, both presentation and recall of the material were verbal. The next preliminary experiments examined other combinations of the modalities of encoding and decoding such as verbal presentation with visual recall or visual presentation with visual recall. It would be interesting to see if this proposed change in the modality of encoding or decoding would lead to any difference in performance of the two versions in comparison to each other or in comparison to performance under different manipulations in the modalities of encoding and decoding. Varying the method of presentation or recall might lead to differences in performance of the two tasks in terms of task difficulty or in terms of the SP effect. For instance, could recalling the items visually, by filling the relevant squares of a real matrix by cards containing the digits or the pictures, bring about any change in performance of either the SB or PB task? This issue was explored by the next experiment.

3.2. Experiment 1-B

The Effect of Visual Decoding on Performance of the Standard & the Picture Brooks Tasks

3.2.1. Introduction:

The results of Experiment 1-a showed that replacing the digits on the Brooks Matrix task by visually distinctive and easily imageable objects produced no significant difference in performance. Moreover, an analysis of the SP effect showed that subjects recalled the first few sentences much better than the last few sentences. This pattern was very similar in both conditions. These results seem to suggest that the kind of material used in the Brooks Matrix (digits or objects) does not make a significant difference on performance, provided subjects are given the opportunity to memorise the order of the objects in order to make them equivalent to the digits. However, it should be noted that in Experiment 1-a, as in the Brooks procedure, both presentation and recall of the material were verbal. The question that arose at this stage was could we obtain the same results if there is a variation in the method of presentation or recall. In other words, the modalities of encoding and decoding could be crucial in determining subjects' performance on both the PB and SB tasks.

This second preliminary experiment explored the effects of varying the method of recall on subjects' performance of both the SB and the PB tasks. Specifically, subjects were required to recall the material "visually" rather than verbally. In this "visual" recall subjects responded by placing pictures of the objects or cards containing the digits in their designated squares on a real matrix. During recall a 4x4 matrix was placed in front of the subject who was given cards containing either coloured pictures of the objects or the digits 1-8. The method of presentation was not changed. The sentences were presented verbally as in Experiment 1-a. As such this experiment examined the second possible input-output combination (verbal-visual). It tested whether changing the method of recall from verbal into visual could produce different effects on performance of the standard and the pictorial versions of the Brooks Matrix task. One hypothesis tested here was that having pictures of easily imageable objects at decoding leads to better recall than having the digits 1-8 of the SB task. Another hypothesis was that with this visual recall, performance on these two versions of the Brooks Matrix would be better than performance with verbal recall as in Experiment 1-a.

3.2.2. Method

Material & equipment:

The same material and equipment used in Experiment 1-a were used here with some exceptions. First, since subjects recalled the sentences by placing cards containing the digits or the objects on a real matrix, a 4x4 square matrix was produced on a stiff card and was always used for this visual recall. The size of this matrix was 22x22cm and the starting square was marked with a cross. A second difference was that responses were not tape-recorded since recall was not verbal. Instead, responses were video-taped using a portable VHS colour (Sony) video camera. Thus, a video-monitor and a VCR were also used.

General procedure:

The testing procedures used in Experiment 1-a were followed with a few modifications. Each subject was initially introduced to the task as in Experiment 1-a. He (she) was shown the 4x4 matrix printed on a stiff card. In the PB condition, each subject was then shown and familiarised with the 8 pictures of the objects, and was required to memorise the order of the objects. The same method of serial-anticipation which was used to achieve this purpose in Experiment 1-a was used. In the SB condition the subject was shown the other set of 8 cards containing the digits 1-8. Following this, each subject was informed that he (she) was to listen to a set of 8 sentences describing the locations of the 8 digits (objects) in relation to one another within the matrix. The subject was instructed that the task was to recall the items and their locations after the last sentence of each test had been presented. Each subject was informed that during recall, the 4x4 matrix along with the cards containing the digits (objects), would be placed in front of him (her) and that the task was to recall the sentences by placing the items in the exact squares indicated by the sentences. During presentation, the cards containing the digits or the pictures of objects were not shown to subjects.

Subjects were instructed to attempt to remember the sentences, which describe the locations of the digits (objects) in relation to each other within the squares of the matrix, by forming a mental image of those items relative to one another within the matrix. They were told that this image could then be used at recall to reconstruct the items and place them on the matrix in the appropriate squares. Subjects were also informed that during recall they could start by placing any item they choose. For instance, in recalling the items of the SB task, they could start by placing the card of the digit 8 or 5 before any other digit. Thus, free-recall was permitted instead of the rigid form of serial recall used in Experiment 1-a. Subjects were however reminded that it was imperative for successful recall to attempt to place the items in the specific squares indicated by the sentences.

The sequences of sentences were played out from a tape-recorder at the rate of 1 sentence per 2.5 seconds. Subjects' responses to the testing trials were video-taped for subsequent analysis. No limit was imposed on response time and specific sets of instructions were used with all participants (see Appendix 2.3).

Subjects:

Fifteen participants (11 males & 4 females) were recruited from undergraduate and postgraduate students at Warwick University and took part in this experiment. They were offered a fee of £2 and none had participated in Experiment 1-a. Their age ranged from 19-34.

Experimental design & set-up:

The design and experimental set-up were similar to the design and set-up of Experiment 1-a apart from some modifications to suit the change from verbal into visual recall as follows:

The video camera was installed on a tripod at the rear-right of the subject so that it overlooked the subject when he (she) placed the items on the matrix during recall. The video-monitor and the VCR were placed within the reach of the experimenter so as to be able to operate and monitor the recording of responses. After introducing the subject to the task, 2 practice trials were then given on the condition on which he (she) was to be tested first. During the first practice trial, the subject was presented with the 4x4 matrix and was asked to listen to the first sequence of 8 sentences. The matrix was placed on the table in front of the subject who was reminded that the task was to place the digits (objects) in the indicated squares after listening to the whole set of 8 sentences. Then a second practice trial was given, using the second sequence, without the matrix being present at input. In this trial, after the last sentence was presented, the matrix and the relevant set of cards were immediately placed in front of the subject in order to begin recall. The cards were always presented in a random order. A photograph showing the subject visually decoding the SB task by placing 8 cards representing the digits on a real matrix is provided in Appendix 2.1.

Following this practice period, each subject was tested six times on the current condition using the remaining six sequences. During this testing the matrix was not present at encoding but, of course, it was presented, along with the cards, to the subject at recall. After the subject had been given one condition he (she) was given the other condition using the same steps in terms of starting with 2 practice trials and then being tested six times. After testing, the experimenter copied down the video-recorded responses on 'answer' sheets identical to those used in Experiment 1-a for subsequent analyses.

3.2.3. Results

A comparison between subjects' performance on both conditions was carried out. Errors were counted for each subject in each condition. An error here refers to any digit (object) that was placed incorrectly on the matrix in terms of its spatial relation to the preceding item (the spatial adjective) or in terms of its identity. In each trial, 8 items had to be recalled. The first item was always placed in the same starting square and thus involved no errors. There are therefore 7 possible errors in each trial and since each subject was given 6 experimental trials, there are 42 possible errors per subject in each condition. Table 3.b shows the mean percentage of errors made at each condition and Figure 3.3. illustrates these data:

Condition	Mean	N	SD
Standard Brooks	16.51	15	12.55
Picture Brooks	13.49	15	12.00

Table 3.b. Mean percentage of errors made at each condition.

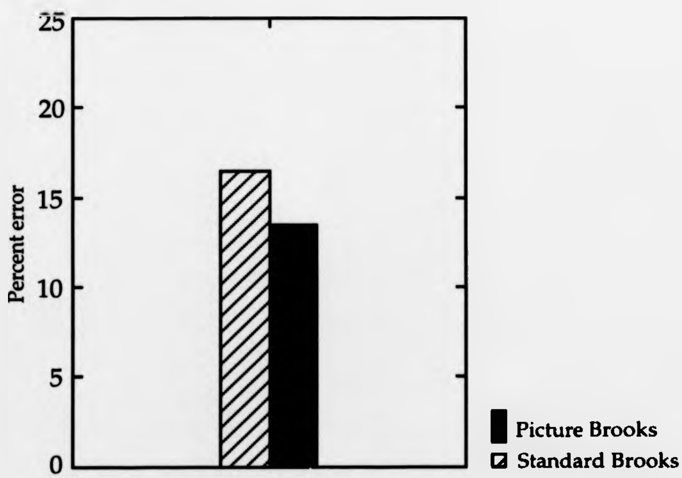


Figure 3.3. Mean percentage of errors made at each condition.

From the above table and figure it appears that there is no large difference between performance on the SB and performance on the PB tasks. A paired samples t-test was conducted on this data and showed no significant difference between the two conditions (t=0.61, df=14, p=0.55).

Subjects in this experiment recalled each set of 8 sentences by placing 8 cards containing digits (objects) on a real matrix. An analysis of SP effect was conducted on the data in both conditions in order to find out whether more errors were made at the beginning or at the end of each set of 8 items. Errors made at each of the 8 serial positions were counted in each condition. Fifteen subjects were tested and each was given 6 trials, thus each position had 90 chances of being error. Figure 3.4 shows the mean percentage of error at each SP in both conditions.

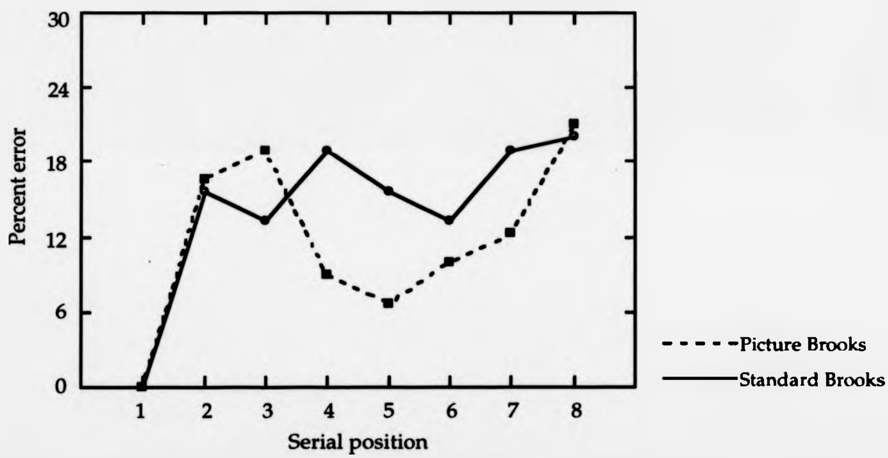


Figure 3.4. The serial position curves for both the SB & the PB conditions.

Figure 3.4 shows that in the PB condition the highest error rates were made at the first and the last few positions whereas positions in the middle had the lowest error rates. Position 1 had, as always, no errors since here it was always the same marked square on the recall matrix, and thus it was excluded from the statistical analysis. In the context of the classical SP effect, this curve seems to be just the opposite pattern. In contrast to the SP effect, the lowest error rates were in the middle not at the beginning or the end of the list of items. This could be due to the nature of the task which emphasised serial recall. In regard to the SB condition, this pattern of recall did not exactly occur. The number of errors made at positions

2-8 seems to fluctuate and no primacy or recency effects occurred. A two-way ANOVA was performed on this SP data with task-type as the independent factor and serial positions 2-8 as the repeated measures variable. This analysis showed no significant main effect of task-type [$F(1,14)= 0.373$, $P=0.55$]. Similar numbers of errors were made in the two conditions. The main effect of SP just failed to reach significance [$F(6,84)=2.15$, $P=0.056$]. In both conditions, almost similar numbers of errors were made at positions 2-8. The interaction between task-type and SP was not significant [$F(6,84)=1.76$, $P=0.12$]. The two curves do not differ significantly.

Performance on the SB and PB conditions in this experiment (verbal-visual) was compared to performance in Experiment 1-a (verbal-verbal). In regard to the PB, it appears that subjects made fewer errors on this condition in this experiment. The mean percentage of error on this condition in Experiment 1-a was 17.94 whilst in this experiment it was 13.49. An independent samples t-test showed no significant difference ($t=0.80$, $df=28$, $p=0.43$). In regard to the SB, subjects made slightly more errors on this condition in this experiment. The mean percentage of error on the SB was 15.24 in Experiment 1-a whilst in this experiment it was 16.51. An independent samples t-test showed no significant difference ($t=0.24$, $df=28$, $p=0.81$). Thus, visual recall did not lead to better performance.

3.2.4. Discussion

Results of this preliminary experiment showed that changing the method of recall from a verbal into a visual modality did not result in a significant difference in performance of the SB and PB conditions. Having the matrix, along with a set of cards, in front of the subject during decoding did not result in a change in performance. Thus, having pictures of easily imageable objects at decoding did not lead to better performance on the PB condition.

In regard to the SP analysis, the two obtained curves showed that high numbers of errors were made at both the first and the last few positions. This is in contrast to Experiment 1-a in which there was a primacy but no 'recency' effect. In Experiment 1-a, error rate increased approximately linearly with SP. In that experiment, subjects were required to recall verbatim each set of 8 sentences word by word in the same serial order in which they were presented. But in this experiment, subjects were instructed that, during recall they could start recalling by placing any item they choose in its indicated place on the 4x4 matrix. However, very few subjects took advantage of this opportunity to dispense with order information. The experimenter observed that the overwhelming majority of subjects preferred to start recalling the items in the same serial order in which they were presented. When asked about the reason, some subjects indicated that during presentation of the sentences they tended to mentally form a spatial pattern of the items within the matrix and that it was more helpful to exactly reproduce that pattern at recall.

Concerning the comparison of performance on the SB and PB in this experiment, in which recall was visual, to performance in Experiment 1-a (verbal input-verbal output), the results showed that there was no significant difference. Visual recall did not lead to a significant improvement in performance. Subjects in Experiment 1-a insignificantly made more errors on the PB than on the SB but the opposite occurred in this experiment in which recall was visual. In this second experiment subjects performed insignificantly better on the PB. The total number of errors made in Experiment 1-a on the PB was 113 with a mean of 7.53 per subject whilst in this experiment the total number of errors on the PB was only 85 with a mean of 5.67 per subject. Visual recall seems to have insignificantly facilitated performance of the PB. For the SB, the total number of errors made in Experiment 1-a was 96 with a mean of 6.40 per subject whilst in this experiment (visual recall) the total number was 104 with a mean of 6.93 per subject. The overall performance of Experiment 1-b seems also to be better than that of Experiment 1-a. The overall number of errors in Experiment 1-a was 209 whereas it was 189 in Experiment 1-b. However, none of these differences reached statistical significance.

In this experiment, subjects were presented at recall with the recall matrix and 8 cards containing the digits or objects. The cards were always presented in a *random* order and thus the subject had to sort the cards and find the right card in terms of its 'order'. Some subjects indicated that this manipulation of the cards interfered with their ability to perform. Manipulating the cards involves movement and it would be interesting to examine whether this movement did interfere with the mental image during retrieval by replicating this experiment and giving subjects the cards in the same presentation order. The experimenter also noticed that some subjects during encoding were using their fingers to 'draw' a spatial pattern of the items on the table. Then they attempted to use that pattern to help in placing the items on the matrix. These subjects indicated that they used this technique or "imagery mnemonic" as a back up to a parallel mental pattern.

In conclusion, results of this experiment (verbal presentation-visual recall) showed no significant difference between performance on the SB and PB conditions although there was some insignificant improvement in performance of the PB. In addition, the results showed that performance on both conditions under the current variation in the modalities of presentation and recall was not significantly different from performance under the first manipulation (verbal-verbal). Visual recall did not bring about a significant improvement in performance. The next experiment examined the effect of presenting the material visually rather than verbally. Recall was verbal instead of visual. Thus, the next experiment examined the effect of the third possible input-output combination (visual-verbal) on performance of the SB and PB tasks.

3.3. Experiment 1-C

The Effect of Visual Encoding on Performance of the Standard & the Picture Brooks Tasks

3.3.1 Introduction:

Results of Experiment 1-b showed that changing the method of recall of the SB and its pictorial variant (the PB) from verbal into visual recall did not result in a significant difference between performance of the two conditions. With this visual recall subjects made insignificantly fewer errors on the PB than on the SB. Also in comparing the results of that experiment to the results of Experiment 1-a, there were no significant differences between subjects' performance on either the SB or the PB conditions. The presence of the matrix during decoding did not bring about a significant improvement in performance.

This third preliminary experiment explored the effects of varying the method of presentation, rather than the method of recall, on subjects' performance in both the SB and the PB conditions. The task was thus presented visually whilst recall was verbal. Subjects were required to watch 8 displays of the matrix on a screen by a slide projector with 1 item being displayed at a time in its successively designated square. Then the task was to verbally describe the locations of the items exactly as in Experiment 1-a. This variation is complementary to the variation in Experiment 1-b (verbal presentation-visual recall).

A question tested here was whether this change in the method of presentation from verbal into visual would bring about any significant effect on performance of one condition in comparison to the other. Another question tested was whether this change into a visual encoding modality would bring about any significant difference in performance of the two conditions in comparison to previous performance under different variations in the modalities of presentation and recall (Experiments 1-a&b). In general, would performance of the matrix task, in its standard or pictorial form, be significantly better under any one of the four possible input-output combinations (verbal-verbal, verbal-visual, visual-verbal, and visual-visual)? This latter question remains to be answered when this series of preliminary experiments is completed.

In this experiment, the task was not presented verbally by having subjects listen to sentences that describe the locations of the items within a "mental" matrix. Instead subjects encoded the material, that described the locations of the digits (objects) in relation to one another within the matrix, visually by watching 8 consecutive displays of the matrix on a screen with each display showing the matrix with only one item placed in its successively designated square. Subjects, however, recalled each sequence verbally as in Experiment 1-a. A hypothesis tested was that having visually distinctive and easily imageable material at encoding would lead to better recall than having the digits of the SB task. Another hypothesis was that visually encoding the task material would bring about a significant improvement in performance of both tasks in comparison to previous performance under different variations in the encoding and decoding modalities (Experiments 1-a&b).

3.3.2. Method

Material & equipment:

The same material and equipment used in Experiment 1-a were used here with some modification as follows:

The items (digits or objects) were presented to subjects visually by a slide projector. This was accomplished as follows: A 4x4 matrix (22x22cm) was prepared without the starting square being marked. The two sets of 8 cards, containing the pictures of the 8 objects or the 8 digits, which were prepared for Experiment 1-a were obtained. The two sets of 8 sequences of 8 sentences that were used in Experiments 1-a&b for the SB and PB conditions were also obtained. After that, each digit (object) was photographed in its designated square within the matrix as indicated by each sequence of 8 sentences for both conditions. Each sequence (test) has 8 sentences that successively describe the locations of the items relative to one another within the matrix. Therefore, 8 different photographs of the matrix were taken for each sequence. These 8 photographs were then transformed into 8 slides. Each slide showed only 1 digit (object) in its designated square.

For each condition, 8 sequences (tests), each consisting of 8 sentences, were required (2 for practice trials & 6 for testing trials). Thus, for each condition 64 photographs were taken which were then transformed into 64 slides. Some additional equipment were thus used which included a camera for taking the photographs, a slide projector, and a portable screen. The projector was connected to the Birkbeck Timer in order to automatically pace the rate of presentation at 1 slide per 2.5 seconds. Two Bell push switches with open contacts were connected to this Timer in order to operate it, and thus operate the projector, remotely. Subjects' responses to the 6 testing trials were simultaneously hand-recorded by the experimenter on A4 sheets each containing 6 small matrices. Responses were also tape-recorded as in Experiment 1-a.

<u>General procedure:</u>

The procedures followed in Experiment 1-a were followed with some modifications. As in Experiments 1-a&b, the subject was initially introduced to the task. He (she) was shown a 4x4 matrix (22x22cm) with the starting square marked with a cross. The subject was then familiarised with the 8 cards containing the digits or the pictures of objects. In the PB condition, the subject was required to memorise the order of the objects using the same method of serial-anticipation used in Experiment 1-a. Then, the subject was informed that he (she) was required to watch 8 consecutive displays of the matrix by 8 different slides that show the locations of the 8 digits (8 objects) in relation to one another within the squares of the matrix. It was explained that the digits (objects) would always be displayed in the same order and that the first digit or the first object (Duck) would always be in the starting square, the second cell on the second row of the matrix, whilst the rest of the digits (objects) would be successively placed in relation to one another within the matrix. It was also explained to subjects how the 8 slides related to the matrix and that the only way in which tests (sets of 8 slides) differed was the sequence of transitions (up-down, right-left) from one square to another.

The subject was informed that the task was to recall the locations of the items verbally after the last slide of each test had been presented. Subjects were instructed to describe the locations of the items within the squares of the matrix by constructing sentences with the following structure:

<u>For the SB condition:</u>
In the stating square put a 1.
In the next square up (down, to the left, or to the right) put a 2;
In the next square to the left (to the right, up, or down) put a 3;
......and so forth until the location of the last digit (8) is described.

<u>For the PB condition:</u>
In the starting square put a duck.
In the next square up (down, to the left, or to the right) put a Train;
In the next square to the left (to the right, up, or down) put a House;
......and so forth until the location of the last object (A Bear) is described.

Subjects were instructed to attempt to remember the 8 displays of the matrix, which show the locations of the 8 digits (objects) in relation to each other, by forming a mental image of these items relative to one another within the squares of the matrix. They were told that this image could then be used at recall to reconstruct the items and put them in the appropriate sentences. This verbal recall is the same as that in Experiment 1-a which demands a rigid serial recall.

Thus, each sequence of 8 digits (objects) was displayed as a sequence of 8 slides at the rate of 1 slide per 2.5 seconds. In each condition, responses to the 6 testing trials were tape-recorded for subsequent analysis. No limit was put on response time. Specific sets of instructions were used with all subjects (Appendix 2.3).

Subjects:

Fifteen participants (11 males & 4 females) were recruited from undergraduate and postgraduate students at Warwick University and took part in this experiment. They were tested individually and none had participated in any of the previous experiments. Their age ranged from 19-34 and each was offered a fee of £2.

Experimental design & set-up:

The design of this experiment was the same as that in Experiment 1-a. The experimental set-up and the testing steps followed in Experiment 1-a were followed here with some modification as follows:

The subject was seated at the rectangular table approximately 2 metres away from the portable screen on which the slides were projected. The slide projector was placed on a special stand behind the subject so that the projection light passed over the head of the subject and the matrix was projected on the middle of the screen. The two Bell push switches were placed near the experimenter in order to remotely control the transition from one test into the other. The presentation of each 8 slides was at the rate of 1 slide per 2.5 seconds, paced automatically by the Birkbeck Timer which was connected to the projector. After each sequence (test) had been presented, a response period followed. Then the next sequence was presented and so on. The tape-recorder was placed near the subject in order to record their responses. During testing, the light in the room was partially reduced to allow clear projection of the matrix. A photograph illustrating the experimental set-up with the subject visually encoding the task is provided in Appendix 2.1.

After the subject had been introduced to the task, he (she) was given 2 practice trials on the condition on which he (she) was to be tested first. The order of administering the two conditions was counterbalanced as in Experiment 1-a. In the first practice trial, the subject was asked to watch the 8 displays of the matrix that show the location of each item in relation to its predecessor within the squares of the matrix. The subject was instructed that after the 8 slides had been displayed, the task was to verbally describe the locations of the digits (objects) within the squares of the matrix using sentences with a specific structure (see the procedure section). No matrix or cards were present at recall. The subject was supposed to rely on his (her) mental imagery to maintain an image of the items within the matrix and to use that image in describing the locations of the items. A similar second practice trial was then given followed by 6 testing trials. After the subject had been given one condition he (she) was then given the second condition following the same steps, starting with 2 practice trials followed by 6 testing trials.

3.3.3. Results

Errors were counted for each subject in each condition. An error refers to any sentence that was incorrectly constructed in terms of its spatial adjective or in terms of the identity of the object (digit) involved. In each trial, 8 sentences had to be constructed. The first sentence was always the same and thus involved no errors. There were therefore 7 possible errors in each trial and since each subject was given 6 testing trials, there are 42 possible errors per subject in each condition. Table 3.c shows the mean percentage of errors made at each condition and Figure 3.5 illustrates these data:

Condition	Mean	N	SD
Standard Brooks	4.13	15	4.27
Picture Brooks	6.19	15	8.81

Table 3.c. Mean percentage of errors made at each condition.

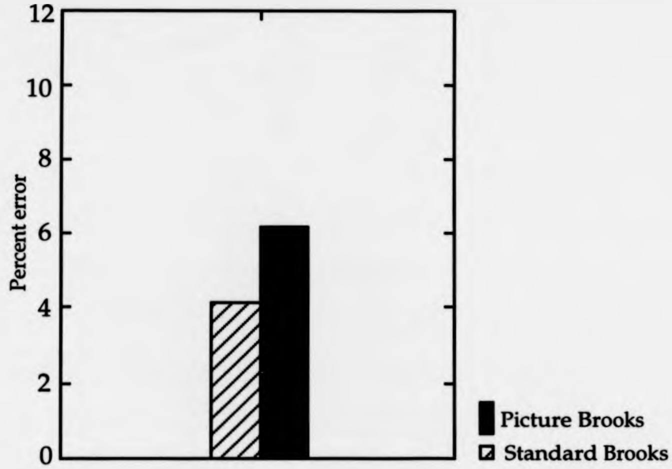


Figure 3.5. Mean percentage of errors made at each condition.

From table 3.c it appears that there is no large difference between performance on the SB and performance on the PB. A comparison was conducted between performance on both conditions. A paired samples t-test was performed on this data and showed no significant difference ($t=0.82$, $df=14$, $p=0.43$).

In this experiment, each visually presented sequence was verbally recalled by constructing 8 sentences that describe the locations of the 8 items in relation to one another within the matrix. An analysis of the SP effect was carried out on the data in both conditions in order to find out whether more errors were made at the beginning or at the end of each set of 8 positions. Errors made at each SP were counted in each condition. Fifteen subjects were tested and each was given 6 trials, thus each position had 90 chances of being error. Figure 3.6 shows the mean percentage of error made at each SP in both conditions.

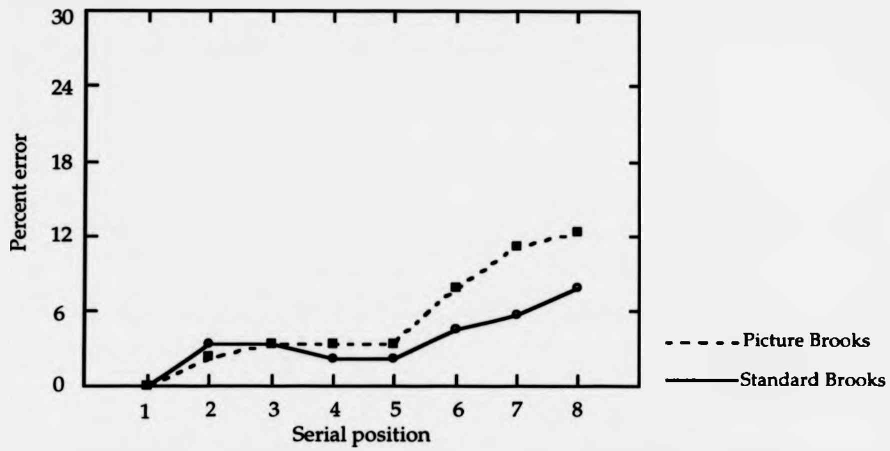


Figure 3.6. The serial position curves for both the SB & the PB conditions.

The two curves shown in figure 3.6 do not appear to differ significantly, with the error rate increasing approximately linearly with SP. No errors were committed at position 1 since it always involved the same sentence and the same starting square. Therefore, position 1 was excluded from the SP statistical analysis. A two-way ANOVA was performed on the data with task-type (SB vs PB) as the independent factor and serial positions 2-8 as the repeated measures variable. This analysis showed no significant main effect of task-type [$F(1,14)=0.81$, $P=0.43$]. Similar numbers of errors were made in the two conditions. There was a highly significant main effect of SP [$F(6,84)=5.76$, $P=0.00$]. In both conditions, significantly more errors were made at some positions. The interaction between task-type and SP was not significant [$F(6,84)= 0.59$, $P=0.74$]. The two curves do not differ significantly.

Performance on the SB and PB conditions in this experiment was compared to previous performance in Experiments 1-a&b. Error rate appears to have decreased in both conditions in this experiment in comparison to performance in Experiments 1-a&b in which encoding was verbal. In comparison to Experiment 1-a, fewer errors were made on the SB in this experiment. The mean percentage of error on the SB in Experiment 1-a was 15.24 whilst it was only 4.13 in this experiment. An independent samples t-test showed a significant difference ($t=2.56$, df=28, p=0.02). Similarly, fewer errors were made on the PB in this experiment in comparison to Experiment 1-a. The mean percentage of errors on the PB in Experiment 1-a was 17.94 whereas it was only 6.19 in this experiment. An independent samples t-test showed a significant difference (t=2.28, df=28, p=0.03). Thus, visual encoding led to better performance on both the SB and PB conditions in comparison to performance under aural encoding.

In comparison to Experiment 1-b, fewer errors were also made in the SB condition in this third experiment. The mean percentage of errors on the SB in Experiment 1-b was 16.51 whereas it was only 4.13 in this experiment. An independent samples t-test showed a highly significant difference (t=3.62, df=28, p=0.00). Visual encoding of the SB led to better performance in comparison to verbal encoding. Similarly, fewer errors were made in the PB condition in this experiment in comparison to Experiment 1-b. The mean percentage of errors on the PB in Experiment 1-b was 13.49 whilst it was only 6.19 in this experiment. However, this improvement was short of reaching statistical significance. An independent samples t-test showed insignificant difference (t=1.90, df=28, p=0.068).

3.3.4. Discussion

In this third experiment, unlike in Experiments 1-a&b, the method of presentation of the Brooks Matrix task was changed into visual presentation. Instead of verbally presenting 8 sentences that describe the locations of the items within the matrix, the items were presented visually by a slide-projector. In each trial, 8 slides were presented on a screen with each slide showing the matrix with one item in its successively designated square. The results showed that this visual encoding did not result in a significant difference between performance on the SB and PB conditions. Under this manipulation, these two versions of the Brooks Matrix seem to be at a similar level of difficulty. Replacing digits on the SB task by simple, easily imageable objects (the PB) produced no significant improvement in performance even when the material were visually encoded. On the contrary, it led to insignificantly more errors.

In regard to the SP analysis, the curves in figure 3.6 appear to be similar to those obtained in Experiment 1-a in terms of the error rate increasing approximately linearly with SP. In both experiments, the method of recall was verbal. Subjects were instructed to attempt forming an image of the items relative to one another within the matrix and use that image at recall to verbally describe their locations. This method of recall demanded serial rather than free recall. In free-recall experiments, items which are toward the beginning of the list (primary) and those which are at the end of the list (most recent) are more likely to be correctly recalled than those in the middle. In this experiment, this pattern did not occur. In both the SB & PB conditions, the lowest numbers of errors were made at the first few positions which might suggest a primacy effect. But the highest numbers of errors were made at the last few positions suggesting a 'negative' recency effect which seems to be a typical result in this series of experiments. This could be due to the nature of the task which demands recalling the items in a serial order with specific spatial relationships.

Comparison of the results of this experiment to the results of Experiments 1-a&b, in which encoding was verbal, showed that visual encoding brought about a significant improvement in performance of both conditions. Presenting the task material visually led to a remarkable improvement in performance. In Experiment 1-a, the Brooks procedure was followed in which subjects were required to visualise digits in a 4x4 "mental" matrix whilst listening to 8 sentences describing the locations of the digits. They also recalled the items verbally by 'reading them off' their visual image. With verbal input, subjects are expected to translate the verbal instructions into a visual image of the items before reading them off that image. Thus, there was a translation of verbal instructions into a mental image although a few subjects in Experiment 1-a indicated that they sometimes relied on rote verbal memory. In contrast, in this third experiment there was no verbal input and instead the matrix was present during encoding and each item was shown placed in its designated square. Thus, during encoding there was immediate visual coding of the material and no need to generate a mental matrix or translate verbal instructions into a visuo-spatial image which might explain the significant improvement in performance. In both of these two experiments recall was verbal.

In Experiment 1-b, the task material were presented verbally as in Experiment 1-a but they were visually recalled by placing cards containing the items in their designated squares on a real matrix. In this third experiment, the complementary input-output combination (visual-verbal) was examined. Thus, in Experiment 1-b the task materials were only present at output whereas in this experiment they were only present at input. Comparison of the results of these two experiments showed that performance under *visual input-verbal output* was superior to performance under *verbal input-visual output*. Hence, the presence of the matrix and task material at encoding facilitated performance whilst their presence only at decoding did not lead to such a positive effect.

In summary, performance in this experiment was highly superior to performance in both Experiments 1-a&b. The critical factor for this seems to be the presence of the matrix and the task material at encoding. The positive effect of the presence of the task material appears to be restricted to input. Quinn (1992) reached a similar result in which the presence of the matrix *during verbal presentation* of the Brooks sentences led to significant improvement in performance. Unlike the visual presentation used in this experiment, Quinn presented the matrix during the verbal presentation or the verbal recall of the sentences. The timing of the diagram's presence was varied to examine whether its contribution to recall was associated with input or output. The positive diagram effect was found to be restricted to input. Quinn argued that the presence of the matrix during verbal input leads to a more adequate differentiation of the digits within the squares of the matrix. The absence of the matrix during verbal encoding, leads to less precise differentiation in cognitive space among the squares.

In this experiment, subjects found the two versions of the task easier than did subjects in Experiments 1-a&b which involved verbal presentation. In addition, subjects indicated that they found the SB to be a little easier than the PB because with the latter they had to pay attention to the *order* of the objects. Also during recall, the experimenter observed that most subjects stared at the screen, on which the task had been displayed, whilst constructing the sentences and describing the locations of the items (reading off the image). Most subjects indicated that during recall they had an image of the items which they described as a shape or a pattern, sometimes within a vague image of the matrix.

In conclusion, in this experiment (visual input-verbal output) there was no significant difference between performance on the SB and the PB conditions. But this visual presentation led to a significant improvement in performance on these two conditions in comparison to previous performance under aural presentation. The next and last preliminary experiment explored the effects of both presenting and recalling the material visually. Would the presence of the task material during both input and output bring about a significant difference in performance of the SB and the PB conditions, and would this visual encoding and decoding lead to further improvement in performance of the two conditions in comparison to performance under previous input-output combinations?

3.4. Experiment 1-D

The Effect of both Visual Encoding & Visual Decoding on Performance of the Standard & the Picture Brooks Tasks

3.4.1. Introduction:

The results of Experiment 1-c, in which the matrix task was presented visually, showed, as did Experiments 1-a&b, no significant difference between the SB and the PB conditions. With visual input, replacing the digits on the SB by pictures of easily imageable objects did not lead to better recall. However, presenting the material visually in that experiment strongly improved performance on both conditions relative to previous performance in Experiment 1-a (verbal-verbal). Also, performance on the SB and the PB conditions in Experiment 1-c was better than in Experiment 1-b (verbal-visual) although for the PB the improvement just failed to reach statistical significance. These results suggest that the crucial factor behind the large improvement in performance is the presence of the task material at encoding. Performance of both the SB and PB conditions under verbal presentation led to low recall. This low recall persisted even though the matrix and the task material were present at decoding in Experiment 1-b. Thus far, it seems as if the positive effect of the presence of the task material is restricted to encoding.

In this fourth experiment, the final variation of the modalities of encoding and decoding (visual-visual) was examined. Unlike Experiments 1-a,b&c, both encoding and decoding of the task were visual. The task was presented to subjects visually as in Experiment 1-c and it was recalled visually as in Experiment 1-b. The Brooks procedure was hence completely changed since there was no verbal presentation or verbal recall. A hypothesis tested here was that, with the task material present at both encoding and decoding, having pictures of visually distinctive and easily imageable objects (PB) would lead to better recall than having the digits 1-8 of the SB task. Another hypothesis was that performance of the two conditions under both visual input and visual output would lead to significantly further improvement in performance relative to previous performance under different input-output combinations (Experiments 1-a,b&c).

3.4.2. Method

Material & equipment:

The task material were presented visually as sets of 8 slides on a portable screen. The same material and equipment used for visual presentation in Experiment 1-c were used here. Recall of the task was also visual as in Experiment 1-b. Subjects responded by placing cards containing the digits (or pictures of the objects) in their designated squares on a real matrix. The same material and equipment used for visual recall in Experiment 1-b were used here. Responses were video-recorded as in Experiment 1-b.

General procedure:

The same procedures followed in presenting the task visually in Experiment 1-c were followed in this experiment. The subject was initially introduced to the task. He (She) was shown the 4x4 matrix printed on a stiff card with the starting square marked with a cross. The subject was then shown the 8 cards containing the digits (or objects' pictures). In the PB condition, the subject was required to memorise the order of the objects using the same method of serial-anticipation used for this purpose in Experiment 1-a. Then, the subject was informed that he (she) was required to watch 8 consecutive displays of the matrix on the screen that show the locations of the 8 digits (objects) in relation to one another within the squares of the matrix. It was explained that the digits (objects) were always displayed in the same order and that the first digit (object) would always be in the same starting square (second cell on the second row) whilst the rest of the digits (objects) would be successively placed relative to one another within the squares of the matrix. It was also explained that the only way in which tests (sets of 8 slides) differed was the sequence of transitions (up-down, right-left) from one square to another.

Each subject was informed that the task was to recall the digits (objects) and their locations after the last display of the matrix had been presented. The subject was informed that at recall, the 4x4 matrix along with the cards containing the digits (pictures of the objects) would be placed in front of him (her) and that the task was to recall the digits (objects) and their locations by placing the cards in the squares of the matrix as designated by the 8 displays. Subjects were instructed to attempt to remember the 8 displays of the matrix, which show the locations of the digits (objects) in relation to one another within the squares of the matrix, by forming a mental image of these items relative to each other within the matrix. They were informed that this image could then be used at recall to reconstruct the items and place them on the matrix in the appropriate squares.

Subjects were informed that during recall they could start by placing any item they choose. Thus, as in Experiment 1-b, free-recall was permitted instead of the rigid serial recall demanded by verbal recall in Experiments 1-a&c. Subjects were reminded however that it was imperative for successful recall to try to place the items in the exact squares shown by the 8 displays.

To summarise, as in Experiment 1-c each sequence of 8 digits (objects) was displayed by 8 slides at the rate of 1 slide per 2.5 seconds. As in Experiment 1-b, subjects recalled the items visually by placing cards on a real matrix. Responses were video-recorded for subsequent analysis. No limit was imposed on response time and specific sets of instructions were used with all subjects (Appendix 2.3).

Subjects:

Fifteen participants (10 males & 5 females) were recruited from undergraduate and postgraduate students at Warwick University and took part in this experiment. None had participated in any of the previous experiments. Their age ranged from 19-32. They were tested individually and each was offered a fee of £2.

Experimental design & set-up:

The design was the same as in Experiment 1-a. The same testing steps followed in Experiment 1-a were followed with some modifications in response to the change in both the methods of presentation and recall. Testing took the following form:

The experimental set-up and the presentation of the task were the same as in Experiment 1-c with one modification to suit the change from verbal into visual recall. No tape-recorder was used since recall was visual. Instead, as in Experiment 1-b, a video-camera was used to record subjects' responses to the 6 testing trials in each condition. It was installed on a tripod to the rear-right of the subject so that it overlooked the subject when placing the cards on the matrix (see Appendix 2.1). The VCR and the video-monitor were placed within the experimenter's reach so as to be able to operate and monitor the recording of responses.

After the subject had been introduced to the task, he (she) was given 2 practice trials on the condition on which they were to be tested first. The order of administering the two conditions was counterbalanced as in Experiment 1-a. During the first practice trial, the subject was asked to watch the first sequence of 8 slides that show the location of each item in relation to its predecessor within the matrix. After the 8 displays had been presented, the subject was presented with the response matrix along with the 8 cards containing the 8 digits (objects) and was asked to attempt to place the items in their designated squares as shown by the 8 slides. Then a similar second practice trial was given followed by 6 testing trials. After the subject had been given one condition he (she) was given the other condition following the same steps in terms of starting with 2 practice trials and then being tested six times. After testing, the experimenter copied down the video-recorded responses on A4 sheets each containing 6 small matrices, for subsequent analyses.

3.4.3. Results

Errors were counted for each subject in each condition. An error refers to any digit (object) that was placed incorrectly on the matrix in terms of its spatial relation to the preceding item (the spatial adjective) or in terms of its identity. In each trial, 8 items had to be recalled. The first item was always placed in the same starting square and thus involved no errors. There were therefore 7 possible errors in each trial and since each subject was given 6 experimental trials, there were 42 possible errors per subject in each condition. Table 3.d shows the mean percentage of error in each condition and Figure 3.7 illustrates these data:

Condition	Mean	N	SD
Standard Brooks	8.73	15	10.40
Picture Brooks	12.22	15	10.33

Table 3.d. Mean percentage of errors made at each condition.

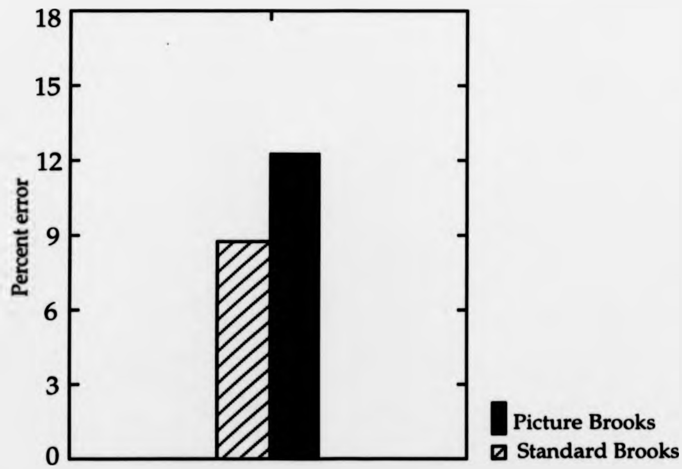


Figure 3.7. Mean percentage of errors made at each condition.

A comparison was carried out between subjects' performance on both conditions in this experiment. From table 3.d it appears that more errors were made in the PB condition. However a paired samples t-test was conducted on this data and showed no significant difference ($t=1.29$, $df=14$, $p=0.22$).

An analysis of the SP effect was conducted on the data in both conditions in order to find out whether subjects made more errors at the beginning or at the end of each set of 8 positions (items). Errors made at each of the 8 serial positions were counted in each condition. 15 subjects were tested and each was given 6 trials, thus each position had 90 chances of being error. Figure 3.8 shows the mean percentage of error made at each SP in both conditions.

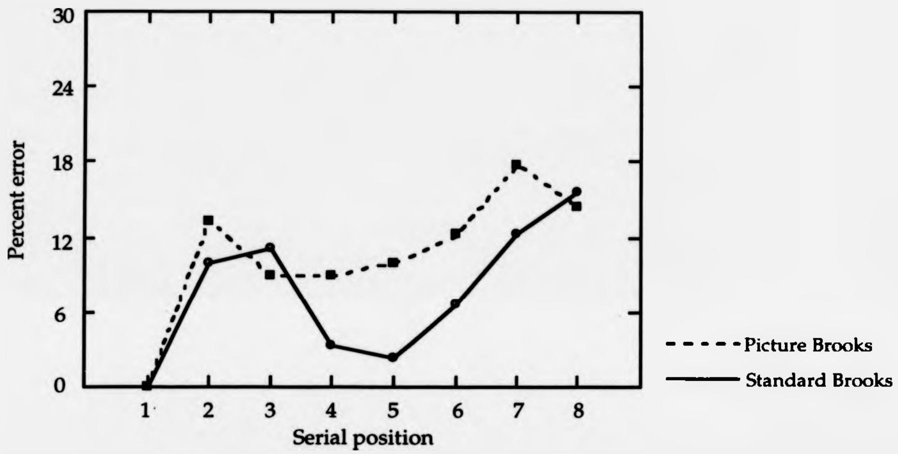


Figure 3.8. The SP curves for both the SB & PB conditions in this experiment.

The two curves in figure 3.8 appear to be, to some extent, similar. In the SB condition, the highest numbers of errors were made at the first and last few items of the sequence which is the inverse of what happens with free-recall experiments. A similar, but not as clear, pattern occurred in the PB condition. Error rate seems to be high at all positions with the first and last few items having the highest numbers of errors. Thus, 'negative' primacy and recency effects occurred although visual recall in this experiment permitted free recall. As usual, no errors were made at the first position since the first item to be recalled was always the same and had no spatial adjective (always placed in the marked starting square). Thus, no error is ever made at this position and it was excluded from this statistical analysis. A two-way ANOVA was performed on the SP data with task-type as the independent factor and serial positions 2-8 as the repeated measures variable. This

2(task-type) x 7(positions) Anova showed no significant main effect of task-type [F(1,14)=1.68, p=0.22]. Similar numbers of errors were made in the SB and PB conditions. But there was a highly significant main effect of SP [F(6,84)=3.12, p=0.01]. Significantly more errors were made at certain positions than others despite the exclusion of position 1. The interaction between task-type and SP was not significant [F(6,84)=1.33, P=0.25]. The two curves do not differ significantly.

Performance in the SB and PB conditions in this experiment was compared to previous performance in each of Experiments 1-a,b&c. It appears from the results that combining both visual encoding and decoding did not lead to further improvement in performance. In regard to the comparison of this experiment to Experiment 1-a, it seems that changing both the encoding and decoding modalities from verbal into visual led to insignificant improvement in performance. For the SB, the mean percentage of error in Experiment 1-a was 15.24 whereas it was only 8.73 in this experiment. An independent samples t-test was performed on this data and showed no significant difference (t=1.31, df=28, p= 0.20). For the PB, the mean percentage of error in Experiment 1-a was 17.94 whereas it dropped to 12.22 in this experiment. An independent samples t-test showed no significant difference (t=1.07, df=28, p=0.29). Thus, performance in this experiment (visual-visual) was insignificantly better than performance in Experiment 1-a (verbal-verbal).

In regard to the comparison of this experiment (visual-visual) to Experiment 1-b (verbal-visual), it appears that the presence of the matrix at both input and output in this experiment brought about insignificant improvement in performance in comparison to Experiment 1-b in which the task materials were only present at output. This improvement was more clear in the SB condition for which the mean percentage of error in Experiment 1-b was 16.51 whilst it was only 8.73 in this experiment. An independent samples t-test was performed on this data and just failed to show a significant difference (t=1.85, df=28, p=0.075). This improvement in performance, although insignificant, did not occur for the PB condition in which the mean percentage of error was 13.49 in Experiment 1-b whilst in this experiment it was 12.22. An independent samples t-test showed no significant difference ($t=0.31$, $df=28$, $p=0.76$). Thus, performance in this experiment (visual-visual) was insignificantly better than performance in Experiment 1-b (verbal-visual).

Finally, the results of this experiment were compared to the results of Experiment 1-c (visual-verbal). The prediction was that the visual-visual combination would lead to further improvement in performance over the improvement resulted in Experiment 1-c from the visual-verbal combination. Results showed that this did not occur and, on the contrary, performance insignificantly deteriorated. For the SB, the mean percentage of error in Experiment 1-c was 4.13 whilst it increased in this experiment to 8.73. An independent samples t-test failed to show a significant difference ($t=1.59$, $df=28$, $p=0.12$). For the PB, the mean percentage of error in Experiment 1-c was 6.19 whilst it increased in this experiment to 12.22. An independent samples t-test just failed to show a significant difference ($t=1.72$, $df=28$, $p=0.096$). Thus, performance in this experiment (visual-visual) was insignificantly worse than performance in Experiment 1-c (visual-verbal).

3.4.4. Discussion

In this final variation in the modalities of presentation and recall, the task was presented visually as sets of 8 displays of the matrix and it was recalled visually by placing cards representing the items on a real matrix. A comparison between performance on the SB and the PB conditions showed that this change in both the modalities of input and output did not lead to a significant difference. The results, thus, did not support the first hypothesis. Under both visual encoding and decoding, using visually distinctive, easily imageable objects (the PB) did not lead to better recall. In fact it led to insignificantly more errors and this may be due to the order of the objects. Despite offering subjects the chance to memorise the order of the objects, some subjects still mentioned that, unlike in the SB, in the PB condition they had to remember two things, the objects' locations and their order.

In regard to the SP effect, subjects in this experiment were informed that at recall they could start by placing any item they choose. Some subjects took advantage of this instruction whereas the majority of subjects did not. Many subjects placed the items in the same order in which they were presented whilst others started recall by placing the last item and subsequently moved backward and the rest of subjects followed other irregular forms of recall. It is clear from figure 3.8 that more errors occurred at the beginning and the end of the sequence despite permitting free recall. This pattern is the inverse of what occurs with verbal free-recall experiments. This may be attributed to the nature of this spatial task that demanded recalling the items in relation to one another within the matrix which may led some subjects to ignore the free-recall instructions.

The pattern of the SP effect that occurred in this experiment is similar to the pattern which occurred in Experiment 1-b in which recall was also visual. With visual decoding subjects seem to make more errors at both the primary and the most recent items which is the inverse of what happens with verbal free-recall experiments. Another unique pattern of SP effect also occurred with verbal decoding in Experiments 1-a&c in which the lowest error rates were at the primary items with the error rate then increasing approximately linearly with SP. This could be interpreted as being due to the rigid serial recall demanded by verbal recall. With verbal recall, the subject was required to read off the visual image from its beginning until its end. This might have led to the gradual fading of the image during decoding and thus to the incorrect recall towards the end. A similar result was reported by Morris (1989) who found that when the recall strategy was changed into *ordered recall* (recalling items in their order of presentation) the SP curves changed with the highest error rate occurring at the most recent items. The resulting curves were similar to those obtained with verbal recall in Experiments

1-a&c in which error rate increased approximately linearly with SP indicating primacy effects and 'negative' recency effects. With visual decoding, where the matrix was present and 'free-recall' was permitted, such a pattern did not occur. Instead, more errors were made at both the beginning and end of the sequence resulting sometimes in nearly a U-shape curve.

Comparison of the results of this fourth exploratory experiment to the results of Experiments 1-a,b&c showed that the presence of the task material at both encoding and decoding resulted in insignificantly better recall relative to Experiments 1-a&b in which encoding was verbal. But performance in this experiment (visual-visual) insignificantly deteriorated relative to performance in Experiment 1-c (visual-verbal). Performance of the SB and the PB was at its best in Experiment 1-c in which subjects watched the displays and then verbally responded by *reading off* the visually encoded image. Presenting the task visually and recalling it verbally brought about a significant change in performance in comparison to presenting the task verbally in Experiments 1-a&b. But this positive effect of visual encoding decreased when recall was changed from verbal into visual as in this experiment.

In contrast to Experiment 1-a (verbal-verbal) both presentation and recall in this experiment were visual. Subjects watched the task material displayed on a screen and then placed the items on a blank matrix. Results showed that changing both the encoding and decoding modalities from verbal into visual led to improvement in performance but this improvement was insignificant for both conditions.

In both this experiment and Experiment 1-b the task was decoded visually by placing cards containing the items on a blank matrix. But these two experiments differed in terms of input modality. The task in Experiment 1-b was presented verbally as sets of 8 sentences. But in this experiment the task materials were present at both input and output which insignificantly led to better recall in comparison to Experiment 1-b in which the materials were only present at output. This insignificant improvement was more clear in the SB, rather than in the PB, condition. These two experiments differed only in terms of encoding modality. Instead of encoding the material through listening to sentences and trying to translate those instructions into a visual image, subjects in this experiment encoded the task directly by watching the items being displayed one at a time in their successively designated squares. However, in both these two experiments recall was visual during which the matrix and 8 cards were presented to the subject who was supposed to sort out the cards in their order and place them in their designated squares. This manipulation of the cards involves movement which may have interfered with the spatial pattern during retention and decoding.

In both this experiment and Experiment 1-c, the task was encoded visually by watching displays showing the matrix with one item at a time placed in its successively designated square. However, the two experiments differed in terms of the method of recall. Performance in Experiment 1-c (visual-verbal) was significantly better than those of Experiments 1-a&b in which presentation was verbal. This improvement was attributed to the presence of the task material at input which perhaps made them available for *direct* encoding into the VSSP. Subjects in that experiment recalled the task by verbally reading off the image. In this fourth experiment the task materials were present at both encoding and decoding. The prediction was that this presence would further enhance performance. Results showed that error rate in both conditions insignificantly increased in this experiment relative to performance in Experiment 1-c.

This deterioration in performance could be attributed to the method of recall in which the two experiments differed. In experiment 1-c subjects recalled the locations of the items verbally and they did not have to manipulate any cards or even move their eyes off the portable screen. Instead, they immediately started recalling mostly whilst staring at the screen as if they were reading off an 'image' that was still there on the screen. In contrast, in this experiment subjects were given a real matrix and 8 cards containing the 'items' and asked to place them on the matrix. This process demanded that subjects move their eyes off the screen and shuffle the cards in their order and place them in the designated squares. These movements of the eyes and hands and the movement of attention during this recall process may have interfered with the retained spatial pattern (image).

In conclusion, in this experiment (visual-visual) there was no significant difference between the PB and SB conditions. Furthermore, combining visual decoding with visual encoding did not lead to further improvement in performance relative to previous performance under different input-output combinations. On the contrary, it led to insignificantly more errors in comparison to visual encoding only (Experiment 1-c) and to insignificantly better performance in comparison to Experiments 1-a&b (verbal encoding). It is thus clear that the crucial element in improving performance is visual encoding. This improvement was only significant when it was combined with verbal, rather than with visual, decoding. The next section provides a thorough comparison of these preliminary experiments.

3.5. Final Comparison

The purpose of this set of exploratory experiments was to examine the Brooks Matrix task which has been heavily used to investigate the WM model. This 'visuo-spatial' task was investigated in an attempt to understand the cognitive processes involved in its performance and thus to devise a simplified variant that would enable examining some hypotheses concerning the nature of the VSSP, particularly the role of movement and the issue of the spatial vs visual nature of this WM subsystem. Simple, readily imageable objects were used instead of digits which resulted in two versions of the task, the SB and PB conditions. In addition, the encoding and decoding modalities were varied between verbal and visual modalities which resulted in four input-output combinations (experiments). In each experiment, the subject was given 6 experimental trials on each condition. In each trial there are 7 possible errors and thus there are 42 possible errors per subject in each condition. Table 3.e shows the mean percentage of error in each condition under each input-output combination and figure 3.9 illustrates these data. In addition, the response time was counted for each trial. Table 3.f shows the mean response time (in seconds) per trial in each condition under each experiment and figure 3.10 illustrates these data.

Experiment	Standard Brooks		Picture Brooks	
1-A Verbal -Verbal	15.24	(16.27)	17.94	(17.93)
1-B Verbal -Visual	16.51	(12.55)	13.49	(12.00)
1-C Visual -Verbal	4.13	(4.27)	6.19	(8.81)
1-D Visual -Visual	8.73	(10.40)	12.22	(10.33)

Table 3.e. Mean percentage of errors in each condition under each input-output combination. (Standard deviations are given in parentheses; N=15)

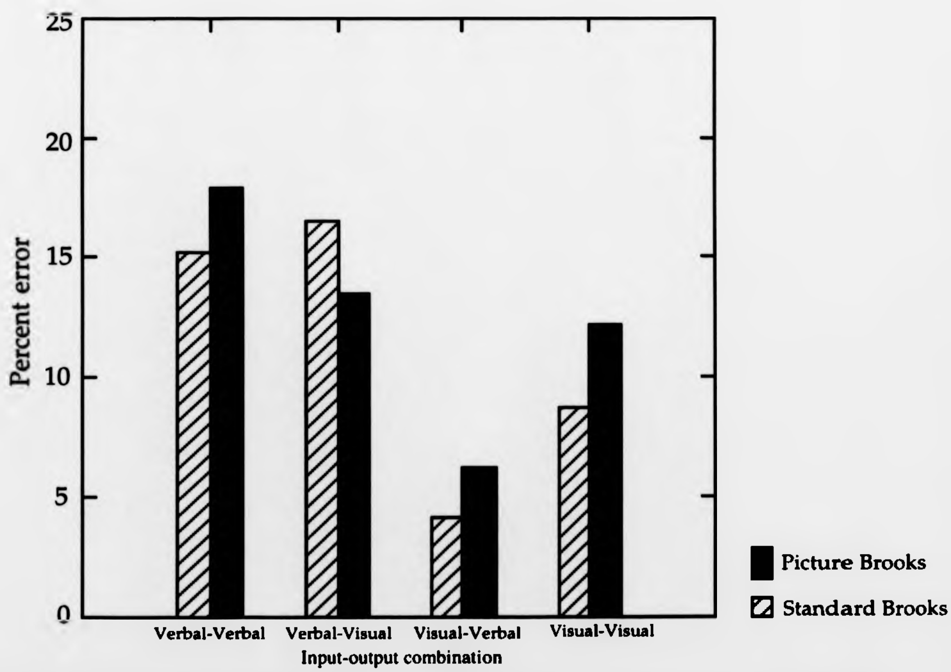


Figure 3.9. Mean percentage of errors made in each condition under each input-output combination (experiment).

Experiment	Standard Brooks		Picture Brooks	
1-A Verbal -Verbal	25.84	(4.83)	40.03	(13.92)
1-B Verbal -Visual	20.07	(5.26)	23.80	(3.96)
1-C Visual -Verbal	24.19	(4.78)	33.19	(7.39)
1-D Visual -Visual	19.27	(5.11)	23.10	(4.54)

Table 3.f. Mean response time (in seconds) per trial in each condition under each input-output combination. (Standard deviations are given in parentheses)

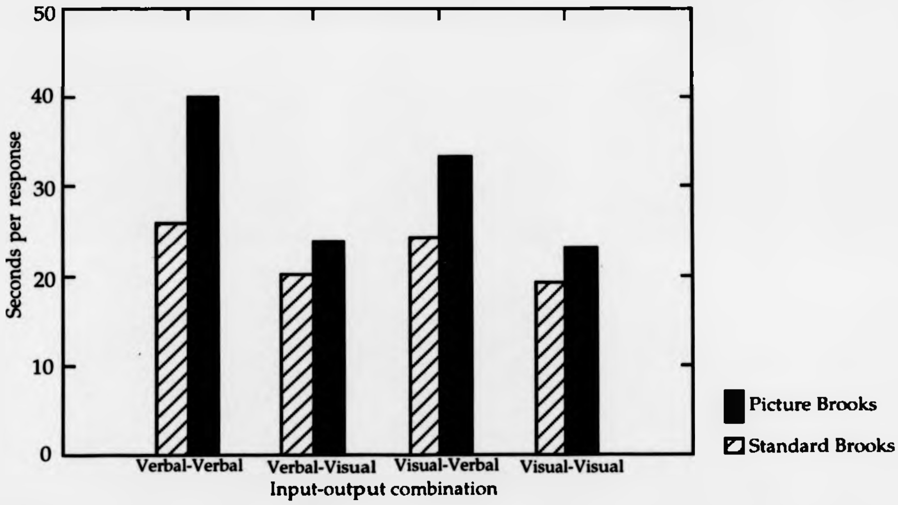


Figure 3.10. Mean response time per trial in each condition under each input-output combination (experiment).

<u>Standard Brooks vs Picture Brooks:</u>

Performance on the SB task was not significantly different from performance on the PB task under any input-output combination. Subjects made relatively more errors on the PB than they did on the SB but, as shown above, none of the differences were significant and it was concluded that the two versions were at a similar level of difficulty. Having simple, easily imageable objects instead of digits did not lead to better recall. On the contrary, it mostly led to insignificantly higher error rates (see table 3.e). This could be related to the fact that the objects are not equivalent to the digits in terms their intrinsic order. Despite giving subjects prior training to memorise the objects' order, this order issue remained as a source of distraction to subjects. Most subjects mentioned that in the PB condition they were dealing with a dual task. That is, remembering both the objects' order and their spatial locations. This problem did not occur with SB since the digits are in an ascending order. It is possible that the PB demanded more than the involvement of a visuo-spatial WM system. Smyth & Pelky (1992) argued that spatial tasks which require recall in order may have different encoding or maintenance demands, and thus may involve not only a spatial system but also make demands on place-keeping functions that are not specific to such system. This implies that maintenance of order information may require involvement of the CE.

Not only did subjects slightly made more errors on the PB but it took them longer to respond. As table 3.f shows, the response time for the PB was always longer than that of the SB. In Experiment 1-a, the mean response time was 25.84 seconds per trial for the SB whilst it was 40.03 seconds for the PB. Two cases were excluded due to missing response time data for 2 trials in the PB condition. A paired samples t-test showed a significant difference ($t=3.23$, $df=12$, $p=0.01$). In Experiment 1-b the mean response time was 20.07 seconds per trial for the SB whereas it was 23.8 seconds for the PB. A paired samples t-test showed a significant difference ($t=2.74$, $df=14$, $p=0.02$). For Experiment 1-c, the mean response time was 24.18 seconds per trial for the SB whereas it was 33.19 seconds for the PB. A paired samples t-test showed a significant difference ($t=4.33$, $df=14$, $p=0.00$). Finally, in Experiment 1-d, the mean response time was 19.27 seconds per trial for the SB whilst it was 23.1 seconds for the PB. A paired samples t-test showed a significant difference ($t=2.87$, $df=14$, $p=0.01$). Thus, it took longer to respond in the PB condition. This also could be attributed to the issue of the objects' order.

Verbal vs visual encoding & decoding:

This section elaborates on the comparison among the 4 encoding-decoding combinations (experiments). Table 3.e above shows the mean percentage of errors made in the SB and PB conditions under each combination. It is obvious from the table that recall was at its best in Experiment 1-c. Performance of the two tasks under the 4 combinations was analysed. A 3x2 ANOVA was performed on the data with encoding, decoding and order of administration (2 levels each) as the independent grouping factors and the two tasks as the dependent repeated measures variables. Order had two levels. Order 1 refers to subjects who were given the SB first and the PB second whilst order 2 refers to subjects who were given the reverse order. The results of this Anova showed a highly significant main effect of encoding modality [$F(1,52)=8.79$, $P=0.005$]. Visual encoding of the SB and PB leads to better performance than verbal encoding. There was no significant main effect of decoding modality [$F(1,52)=0.58$, $P=0.45$]. Visual recall is not different from verbal recall. Order of administration had no significant main effect [$F(1,52)=0.113$, $P=0.74$]. Taking a task second does not lead to better recall. Task-type (SB vs PB) had no significant within subjects main effect [$F(1,52)=0.86$, $P=0.36$]. The SB and PB tasks are not significantly different.

In regard to interactions, the ANOVA showed no significant interactions between: encoding & decoding [$F(1,52)=1.48$, $P=0.23$], task-type & encoding [$F(1,52)=0.72$, $P=0.40$], task-type & decoding [$F(1,52)=0.37$, $P=0.55$], and task-type, encoding & decoding [$F(1,52)=1.02$, $P=0.32$]. The only significant interaction was between task-type (SB vs PB) and presentation order [$F(1,52)=5.81$, $P=0.02$]. This interaction (see figure 3.11) implies that the PB was significantly harder when it was given first. The SB appears also to be insignificantly harder when it was taken first. Taking the PB second results in a sharper drop in error rate in comparison to taking it first. This does not equally occur with the SB task. Subjects who took the PB first may found it harder due to the fact that they were not very familiar with the experimental task plus that they had to keep remembering the objects' order. Taking the PB second, on the other hand, occurs after the subject had taken the SB and thus had become familiar with the task which resulted in a larger decline in error rate relative to taking it first. In regard to the SB, subjects did not find it as hard when it was administered first probably because they only had the disadvantage of the lack of familiarity with the task but there was no other disadvantage such as constantly remembering the order of objects as occurs with the PB. Taking the SB second resulted in better recall but the decline in error rate was not as significant as that occurred with the PB. Thus, order of administration had no significant effect but it interacted with task-type. It is also apparent from figure 3.11 that taking either task second results in an insignificantly better performance which indicates insignificant practice effect.

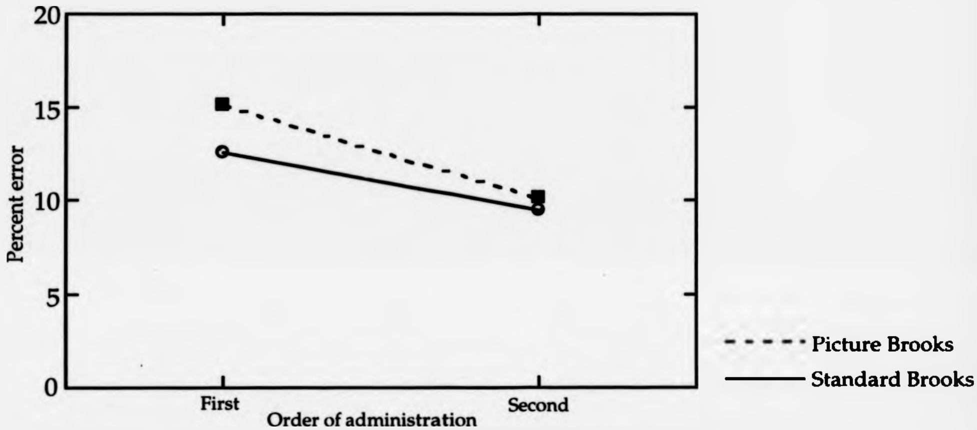


Figure 3.11. Mean percentage of error made when either task is administered first or second. The interaction between task-type and order of administration.

In summary, only encoding modality had a highly significant main effect. Visual, as opposed to verbal, encoding leads to better performance for both tasks. The absence of the matrix at verbal encoding might lead to a less precise differentiation in cognitive space among the squares of the matrix (Quinn, 1992). With verbal presentation, subjects are supposed to listen to the sentences and try at the same time to generate an image of the matrix. This process of translating verbal instructions into a visual image was removed with visual presentation in which the task material was presumably available for direct encoding into the VSSP. The second main result was that there was no significant main effect of task-type. The PB and SB tasks were at similar levels of difficulty. Using visually distinctive, highly imageable material did not enhance retention in the VSSP. Retention was not improved by using strongly visual material as would be expected of a visual store. These two main results might seem in some ways contradictory. On the one hand, the finding that highly imageable pictures are no better recalled than digits seems to suggest that the Brooks task involves processes other than the VSSP. On the other hand, the clear superiority of visual over verbal encoding is consistent with the idea that retention does depend on the short-term storage of a visual image as most subjects report on the basis of their subjective experience.

In regard to response time for each task under the 4 experiments, a similar 3x2 ANOVA was performed on the data shown in table 3.f, with encoding, decoding and order of administration as the independent grouping factors and response times for the 2 tasks as the repeated measures variable. The results showed a highly significant main effect of decoding [$F(1,50)=57.72$, $P=0.00$]. Visual recall is faster than verbal recall. There was a significant effect of encoding [$F(1,50)=4.37$, $P=0.04$]. Visual presentation leads to shorter response time. There was also a significant effect of task-type [$F(1,50)=66.08$, $P=0.00$]. Subjects took more time to respond to the PB than to the SB. Order had no significant main effect but it interacted with task-type [$F(1,50)=27.52$, $P=0.00$]. Response time for the PB is longer when it is given first. Also, there was an interaction between task-type and decoding [$F(1,50)=16.74$, $P=0.00$]. Verbal recall leads to longer response time for the PB than for the SB. In general, visual decoding required less response time which could be due to two factors. First, with visual decoding the matrix was present and this might have made subjects quick and more decisive in recalling the items and placing them in their designated squares. During this decoding, subjects do not need to constantly maintain an image of the matrix due to the presence of the matrix which seems to facilitate faster recall. Second, with verbal decoding subjects are supposed to translate their visual image into verbal sentences which seems to be more time consuming than placing the 8 cards. Subjects were slow in 'reading off' the image and they either closed their eyes or stared at a specific place during decoding. The experimenter observed that during verbal recall some subjects occasionally paused and restarted from the beginning which contributed to the longer response time. This rarely occurred with visual recall.

Subjects were asked after each experiment about the strategy they used in processing the task. Under the first combination (verbal-verbal), 3 out of 15 subjects indicated that they mainly relied on rote verbal memory in recalling the sentences whilst the majority reported main reliance on their visual imagery by forming a mental pattern and using it during recall. Under the third combination (visual-verbal), only 1 subject indicated main reliance on verbal WM. In Experiments 1-b&d, in which recall was visual, none of the subjects indicated total reliance on verbal WM but a few mentioned occasional reliance on verbal WM. In all experiments, the overwhelming majority of subjects reported relying on visual imagery to perform the task and often referred to the image as a shape or a pattern representing the 'items' relative to one another. Difficulties with recall are often attributed to losing the shape or to the end of the shape fading which is consistent with the higher error rate at the last items shown in the SP curves.

In terms of individual differences, the experimenter observed that some subjects found the task easy and made no errors and such subjects indicated relying on their visualisation to perform the task. Other subjects found the task to be difficult and made many errors and such subjects appeared to have no clear strategy and to be less decisive or confident about their ability to perform. However, no scores of a mental imagery test were available for subjects in order to see if their performance on the matrix task correlates with their imagery ratings.

An alternative scoring method:

In the above 4 experiments, the Brooks procedure was used in scoring subjects' responses. With visual recall, an error referred to any item that was placed incorrectly in relation to the preceding item (the spatial adjective). With verbal recall, an error referred to any sentence that was incorrectly repeated particularly in terms of its spatial adjective. If the subject made a mistake at, for instance, the fifth sentence and then correctly repeated the remaining sentences, only 1 error was recorded even if the subject had gone outside the *mental matrix*. Thus, with this method performance was not evaluated on the criterion of exactly placing each digit in its designated square but rather in terms of its *relation* to the preceding digit. This method appears more appropriate with verbal recall. An alternative method of scoring which seems more appropriate for visual recall would be to score responses in terms of *placing* each item in the exact square designated within the matrix regardless of its *spatial relation* to the preceding item. If an item is not placed in its designated square, an error is recorded. Thus during verbal recall, if the subject exited the "mental" matrix, errors are recorded even if the subject correctly repeated the remaining sentences. Responses in the above experiments were re-scored using this *'matrix scoring'* instead of the 'spatial adjective' scoring method. Figure 3.12 shows the mean percentage of error in each condition under each experiment:

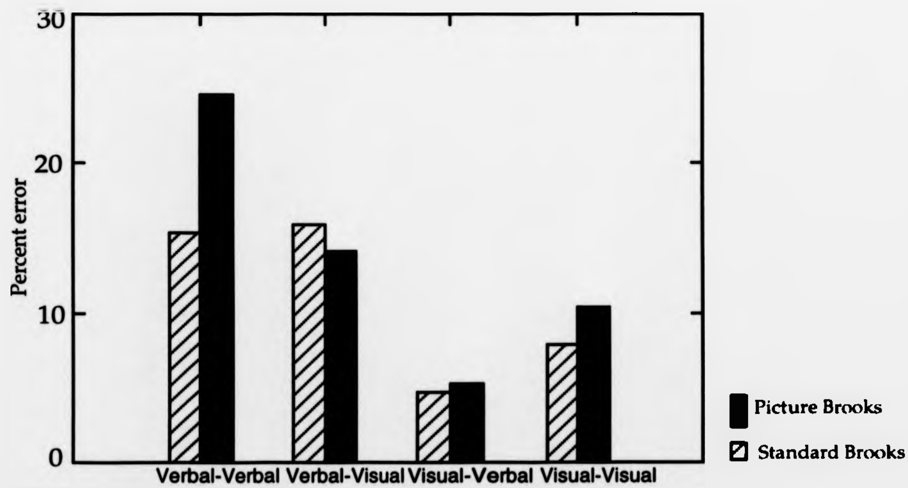


Figure 3.12. Mean percentage of error in each condition under each input-output combination using an alternative scoring method.

The same pattern of results appeared after the alternative scoring with visual presentation leading to lower error rate. However, with the new scoring error rate under verbal presentation increased, particularly for the PB task, whilst decreasing for both tasks under visual presentation. A 3x2 ANOVA was performed on this alternative scoring data with encoding, decoding and order of administration (2 levels each) as the independent factors and the two tasks as the repeated measures variable. Again the ANOVA showed only a highly significant main effect of encoding modality [$F(1,52)=12.92$, $P=0.00$]. Visual encoding leads to better performance. Decoding modality had no significant effect [$F(1,52)=0.01$, $P=0.94$]. Visual recall is no better than verbal recall. Order of administration had no significant main effect [$F(1,52)=0.43$, $P=0.52$] but it again interacted with task-type [$F(1,52)=4.06$, $P=0.049$]. The PB is harder when it is given first. Task-type had no significant within subjects effect [$F(1,52)=2.13$, $P=0.15$]. There is no difference between the SB and the PB. In short, the same pattern of results was obtained.

Conclusion

One conclusion from these four experiments is that the SB task and its pictorial variant are at a similar level of difficulty. Replacing digits on the Brooks Matrix with visually distinctive, easily imageable objects did not lead to better recall. A second conclusion is that visual, as opposed to verbal, presentation brings about a highly significant improvement in performance. The presence of the task materials had a strong positive effect on performance but this effect appears to be restricted to encoding. Their presence at decoding did not lead to better recall.

Thus, visual coding of the matrix task leads to better recall. Quinn (1992) reached a relatively similar result when he had the diagram present *during verbal encoding*. Quinn's initial interpretation was in terms of a visual code: to the extent that the image of the digits is analogous to an external stimulus of the same information, it is sensible that the presence of the matrix contributes to an efficient performance. With visual coding it has been known for some time that the provision of location cues aids recall of items belonging in the locations (Jones, 1976). But another factor, diagram complexity, was manipulated. Instead of using a matrix of regular shape, Quinn used a variety of block diagrams which vary in complexity. Complexity was defined as requiring subjects to move irregular distances and directions as they are instructed to place digits in the 'mental matrix'. The results showed that the positive effect of the presence of the diagram was restricted to input rather than output. The results also showed that when the distance separating the component blocks in the diagram was complex, recall was poorer. Quinn's interpretation of these results was in terms of a movement or spatial code. A more adequate differentiation of the digits within the squares of the matrix is to be expected when the diagram is present during verbal input. The absence of the matrix during verbal coding, Quinn argues, makes the differentiation in cognitive space among the squares less precise. Thus, when moving from position to position according to the verbal input and with no matrix present, the lack of precision leads to less differentiated positioning and subsequent low recall.

In summary, two main results were obtained from this series of experiments. The first was that the pictorial variant of the Brooks task is not significantly different from the standard task. Using pictures of simple, visually distinctive objects did not facilitate recall. As such, this PB variant was no longer used in subsequent experiments. The second result was that visual, as opposed to verbal, presentation of the task led to a significant improvement in performance. This was true for both the SB and PB versions. The next chapter provides an attempt to interpret this second result. A process model of the Brooks Matrix task is proposed to account for the apparent superiority of visual encoding over aural encoding. This model is then examined by the next experiment.

Chapter 4

4.1. A process model of the Brooks Matrix task

Introduction:

The aim of this study was to investigate the nature of the visuo-spatial component of the WM model (Baddeley & Hitch, 1974) particularly the role of movement in this hypothetical subsystem. Experiment (I) attempted to examine the cognitive processes involved in performance of the Brooks Matrix task which has been extensively used to explore the WM model in general and the VSSP component in particular. This task (Brooks, 1967) involves subjects having to visualise the digits 1-8 in a 4x4 mental matrix. A series of 8 sentences describing the placement of the digits in adjacent squares around the matrix, are verbally presented. The sentences could be represented as a mental path through the matrix and subjects are required to repeat verbatim the sentences by reading them off their visual image. Experiment (I) sought to examine this presumably visuo-spatial memory task in two ways. First, the digits were replaced by simple, easily imageable objects. Second, the methods of presentation and recall were varied between visual and verbal modalities resulting in four input-output combinations (experiments): verbal-verbal, verbal-visual, visual-verbal, and visual-visual.

Results of Experiment (I) showed that: 1) Under all of the four variations, replacing the digits on the SB task with simple, readily imageable objects did not lead to better recall. Using visually distinctive material did not enhance retention in the VSSP; 2) The second and important result was that there was only a highly significant main effect of presentation modality. Visual, as opposed to verbal, presentation of information, whether pictures or digits, made the Brooks task very much easier. The presence of the task materials at encoding had a positive effect on performance. This effect appears to be restricted to encoding since their presence at decoding did not lead to any significant improvement.

These two main results might seem in some ways contradictory. On the one hand, the finding that highly imageable pictures are no better recalled than digits seems to suggest that the Brooks task involves processes other than the VSSP. On the other hand, the clear superiority of visual over verbal presentation is consistent with the idea that retention does depend on the short-term storage of a visual image as most subjects report on the basis of their subjective experience. What appears to be happening is that the verbal input-visual image translation is the major difficulty presented by the task. Once in store the retrieval method seems to matter less. This apparent asymmetry of the *A-L bridge* (see chapter 1) indicates that to generate images from words is an effortful, resource consuming process whereas attaching words to images involves much less effortful, perhaps even automatic, processes. The following is an attempt to interpret the superiority of performance with visual presentation. A process model of the cognitive processes thought to be involved in performance of the Brooks task is proposed.

The striking difference between verbal and visual encoding, regardless of the visual qualities of the encoded items, strongly suggests that it is the encoding process itself which provides the principal limitation on the capacity of the VSSP. Aurally encoding the task seems to involve different cognitive codes and processes from encoding it through visual input. With verbal encoding, subjects are required to listen to sentences describing the locations of the digits in adjacent squares around the matrix. Within the proposed process model (see Figure 4.1), at encoding subjects listen to this verbal input and at the same time attempt to *generate* an image of the digits within the matrix from LTM. The image is then sent through a sensory buffer into *recent memory* where it is rehearsed and maintained for decoding. This process of image generation associated with verbal encoding would require the use of CE resources and processes such as coordinating and scheduling to switch attention between external sensory input (Brooks sentences) and internal memory input (images generated from LTM). These CE processes are not assumed to be required when the task is visually encoded.

As explained in chapter 1, the CE is considered to be the core of WM which performs crucial functions including: the regulation of the slave systems and the integration of information from these systems and from LTM, the co-ordination of WM updating in real time, the communication with LTM and other elements of the cognitive system, and the selection, planning, and control of various processes used in short-term storage and more general processing tasks.

The CE is, therefore, thought to play a major function in some WM tasks such as the Brooks Matrix which requires subjects to *generate* images at 'verbal' encoding and retrieval. Within the proposed process model, the CE plays an important role in controlling the entry of both external sensory data (Brooks sentences) and internal memory data (images generated from memory) into the sensory buffer. This buffer is interpreted as the current focus of attention or conscious experience. It is analogue in the same kind of way that the picture on a television screen is an analogue of the original scene. The sensory buffer is considered to be unitary with respect to the different modalities, that is it represents all modalities which contribute to the perception of a given scene.

The contents of this sensory buffer constitute whatever data the CE has allowed through. These could be externally generated stimuli (via a sensory input channel) or internally generated images. This view is very similar to the assumption of the WM model regarding the functioning of the VSSP. Baddeley (1990) indicated that like the AL, the VSSP can be fed directly through perception or indirectly through the generation of a visual image. Hence, the contents of this buffer are continuously changing to represent the current state of affairs (the specious present). Figure 4.1 shows a schematic diagram of the proposed model which illustrates the pivotal role of the CE in processing some WM tasks such as the standard Brooks Matrix task:

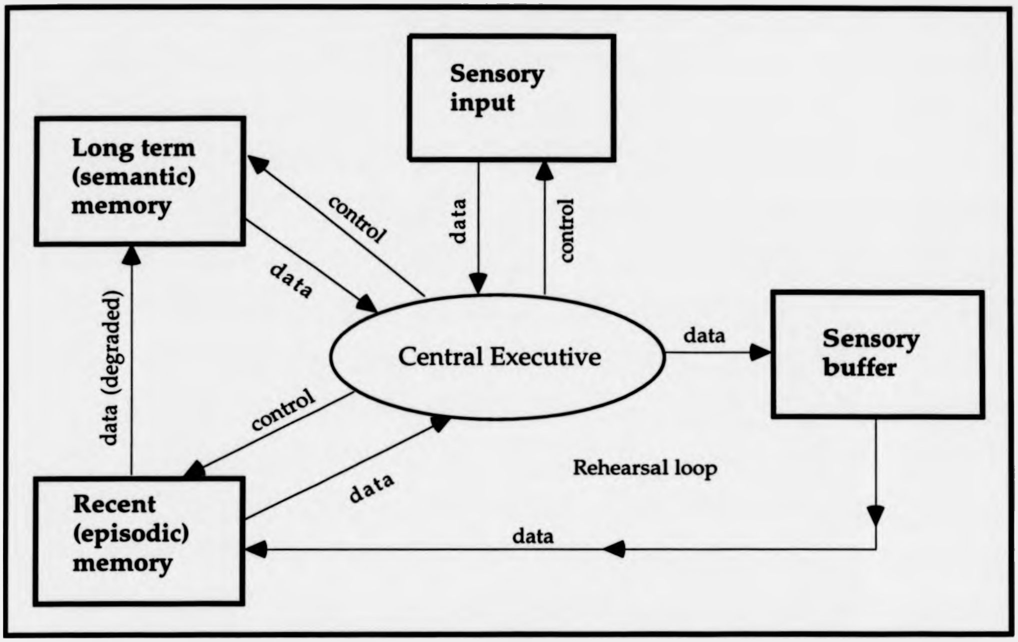


Figure 4.1. A schematic diagram of the proposed process-model illustrating the major role played by the CE in cognitive processing.

According to this account, the function of the CE is simply to switch between different sources of input. These sources are external (sensory) sources and internal (memory) sources. There can be different sensory sources (channels) and the CE can switch between them. Two kinds of internal memory sources are distinguished, recent and long-term memory. These are distinguished principally by differences in the coding of temporal information. Recent memory is viewed as largely episodic and includes a lot of temporal information such as remembering what we were doing a few seconds or a few hours ago and the order in which events occurred. LTM, on the other hand, is largely semantic, that is objects and events are remembered in relation to their meaning or significance whilst temporal order is less reliable as a retrieval cue. Unlike the sensory buffer, the contents of these two kinds of memory are not conscious and must be 'retrieved' and displayed in the sensory buffer to become objects of conscious attention. Retrieval from recent memory is considered to be easy since much of the original sensory coding is preserved. However, retrieval from LTM is more difficult since it requires the generation of images via a semantic network which can result in a novel combination of features.

The sensory buffer is the source of data for recent, episodic information regardless of whether the data were derived from new sensory input or were recycled (generated) from LTM in the form of images. The feedback from the sensory buffer to recent memory thus provides a rehearsal loop (Figure 4.1). The operation of this loop necessarily involves the CE since sensory data must be switched off so that data from recent memory can be brought into the buffer and form the focus of current attention.

In the proposed process model, the key function of the CE is to switch between sources of data that are to be 'displayed' in the sensory buffer. With verbal encoding of the Brooks task, the subject is required to switch between current verbal input and memory input which is the visual image (of the matrix) the subject is assumed to generate from LTM upon hearing the verbal instructions "...in the next square up put a ....". If switching fails, for instance if an image cannot be generated from memory before the next digit is provided aurally, then that item will presumably be lost, at least to visual WM, but some trace might remain in recent memory in an acoustic form. Therefore, verbal encoding of the matrix task would be very sensitive to: a) the rate of presentation of the sentences and, b) the subject's individual ability to generate images at an appropriate rate. These are two empirically testable consequences of the model.

Visual encoding of the task, on the other hand, requires only little or no image generation and thus no switching of attention since the task materials are directly encoded from the visual display. Hence, the CE involvement is assumed to have been minimised. Switching of attention may occur but there is no longer a need to switch attention in order to search for information from which to generate images. Image generation is also required at verbal recall which demands no switching since there is no other incoming data. This account, specifically the elimination of the image generation element and thus the heavy CE involvement at encoding, could explain the results of Experiment (I) which showed superior recall under visual presentation. Presumably, the task is no longer reliant upon subjects' ability to switch attention between external and internal inputs and generate images from LTM at an appropriate rate. This switching is thought to be very sensitive to presentation rate.

Memory failures due to concurrent task demands can logically have two possible sources. First, the CE has switched to another source, e.g. switched into current sensory input rather than retrieving material from recent memory; second, some vital part of the information has not been encoded. A general issue is how different kinds of information are encoded in the sensory buffer, recent memory, and LTM. For instance, object identity could be encoded in all three memory stores whilst characteristics such as colour and pitch might be restricted to the first two. The sensory buffer is presumably a good temporary store for spatial information whereas the recent memory store is needed to store information about temporal order and much of this information is lost by the time the information is preserved only in LTM which is largely semantic in nature.

In Experiment I, visual, as opposed to verbal, presentation of the Brooks Matrix led to better performance. In terms of the process model, with visual encoding subjects do not have to listen to auditory instructions and at the same time attempt to generate images of the matrix from LTM. That is, there is no switching between external information (verbal input) and internal information (generated images) as presumably happens with verbal encoding. Instead, the task materials are present on the screen for direct encoding into the sensory buffer. The information is temporarily maintained by the rehearsal loop until it is decoded.

As explained in chapter 2, the CE has been suggested to be heavily involved during encoding of the Brooks Matrix by numerous researchers (e.g. Logie, 1995; Logie & Marchetti, 1991; Logie et al, 1989, 1990; Morris, 1986a; Quinn, 1988a, 1991; Salway, 1990, 1991). In regard to maintenance, it has been indicated (Logie & Marchetti, 1991; Quinn, 1988a, 1991; Smyth & Pendleton, 1989) that this task is much less prone to interference from visuo-spatial tasks during maintenance. It is argued that once the task is encoded and the directions are formed, they are maintained as a static visual pattern of digits in an imaged matrix rather than a sequence of discrete relative directions. A passive visual store (Logie, 1989) is thought to be responsible for maintenance of this pattern which might explain the lack of interference by spatial tasks during maintenance.

In summary, verbal encoding of the Brooks task is assumed to require heavy CE involvement to switch between sources of data that are to be displayed in the sensory buffer. The subject is required to switch between current verbal input and memory input which is the visual image the subject has to generate from LTM upon hearing the sentences. The difficulty encountered by subjects with verbal presentation would appear to be due to a difficulty in maintaining proper switching between verbal instructions and image generation. This difficulty increases if the subject has a slow rate of image generation. This might explain the relatively high variance among subjects in Experiments 1-a&b in which presentation was verbal. Unlike high imagers, low imagers may have found the task to be hard due to their slow rate of image generation.

Visual input, on the other hand, does not require such heavy CE involvement. Visually encoding the matrix task may involve some switching of attention but there is no longer any need to switch attention in order to search for information from which to generate images. At encoding no image generation is required since the task materials are present on the screen for direct encoding onto the sensory buffer (or VSSP) with minimal CE involvement. The striking difference, shown by

Experiment I, between verbal and visual encoding, regardless of the visual qualities of the encoded items, strongly suggests that it is the encoding process itself which provides the principal limitation on the capacity of the VSSP. Looked at from the point view of the Annett's ALI model (chapter 1), the initially verbal input has to be used to generate a visual image and thus the information has to cross the *A-L bridge* before an image can be entered into the sensory buffer whilst when the material is presented visually this process is eliminated. A more conventional way of looking at this issue would be that this verbal input-visual image translation requires a switch of attention. The problem is then to distinguish between interference with the sensory buffer and interference with the translation process or the resource needed to generate images.

Hence, with this account of the cognitive processes involved in performance of the Brooks task, it seems possible to form and examine some hypotheses regarding why and what sort of movement interferes with the encoding of this task. As explained in chapter 2, many studies have investigated the involvement of movement in the functioning of the VSSP. Most of these studies used the Brooks task with the overwhelming results showing that various concurrent movement tasks interfered with encoding of the visuo-spatial material (e.g. Baddeley et al, 1975b; Baddeley & Lieberman, 1980; Quinn 1988a, 1991, 1994; Quinn & Ralston, 1986). Maintenance of this material has been found to be less prone to movement interference (e.g. Morris, 1987; Quinn, 1988a, 1991). Thus, the locus of movement interference appears to be confined to the encoding, and possibly the retrieval, stage. Morris, Quinn and others argued that the VSSP does require some central capacity during active encoding and retrieval operations but not during maintenance rehearsal when only minimal resources are necessary. Within the process model, it is assumed that verbal encoding of the Brooks task is not only a function of the VSSP but it requires heavy CE involvement to switch attention between the current verbal input (sentences) and the generation of visual images from LTM. Image generation is also required at verbal decoding which might demand some CE involvement. Thus, it is not clear whether movement interferes because the two concurrent tasks require a common visuo-spatial resource in WM (VSSP) or that interference is due to the CE involvement.

Morris (1986a) pointed out that a major problem with the early Baddeley experiments was that all the tasks used, including the Brooks Matrix, have a large verbal component. The spatial tasks used require initial verbal encoding with transformation into spatial representations. This implies that the stimuli must first be represented in the central processor with subsequent rapid registration onto the VSSP. Morris argued that most movement (tracking) tasks do have specific effects on spatial representation, but they may also have general effects when the central capacity is heavily burdened with a memory task that cannot be readily offloaded into a slave system or LTM. In this regard, the verbally encoded Brooks task could be considered as a task that heavily burdens the CE whilst the visually encoded task is assumed to represent a task that could easily be offloaded into the VSSP.

With visual encoding of the Brooks Matrix task, the CE involvement has presumably been minimised since there is no need for switching attention to generate images from LTM. Hence, if a spatial movement, that requires minimum attention, interferes with this task during visual encoding, the interference will not be due to interference with CE attentional processes, but most likely to the fact that the two concurrent tasks use a common visuo-spatial WM resource.

4.2. Experiment 2-A: Examining the process model.

The effect of various movement tasks on the verbal and visual encoding of the Brooks Matrix task.

4.2.1. Introduction:

This experiment examined some hypotheses generated by the proposed process model. It was argued that since CE involvement has presumably been minimised in the visually encoded matrix task, it would be possible to examine whether concurrent movement interferes with the visuo-spatial representation as such, not just by adding to the load on the CE as occurs with verbal encoding. Visual encoding of the Brooks Matrix presumably minimises CE involvement and thus makes the task more dependent on the VSSP. If a task involving repetitive sequential movement to targets in space interferes with this visual encoding, then it could be argued that an independent spatial component of WM and imagery, that is related to movement control, does exist.

As discussed in chapter 2, it is not clear whether secondary movement tasks interfere with primary visuo-spatial tasks, such as the Brooks Matrix, because both concurrent tasks utilise a single visuo-spatial WM resource or simply because they load general purpose resources. Many primary visuo-spatial tasks (e.g. the Brooks Matrix) and secondary movement tasks (e.g. the Moar Box tracking) have been indicated to require heavy CE involvement. For instance, the Moar Box has been widely used as a secondary task that should utilise the VSSP. Yet, the evidence presented by Morris (1987) shows that it also places heavy demands on the CE. Quinn (1991, 1994) while discussing this issue, pointed out that most of the experiments which investigated interference in the VSSP (e.g. Idzikowski et al, 1983; Morris, 1987 & Quinn, 1988a) tended to show that various movement tasks interfere with visuo-spatial memory tasks, such as the Brooks Matrix, and that the encoding stage is isolated as the locus of interference. Yet all of these studies contain a confounding factor, the interfering tasks are effortful and are thus likely to have involved the CE.

Therefore, there is an obvious need to use both primary and secondary visuo-spatial tasks that make minimum demands on CE resources in order to be able to conclude that a secondary movement task interferes with a primary visuo-spatial task because both utilise a common spatial, motoric, WM resource. Quinn (1991) indicated that "clearly, any experiments which have as their goal a more precise delineation of interference effects in the VSSP must attempt to minimise the contribution of attention"(p.99). Similarly, Quinn (1994) argued that clarifying the relationship among attention, movement, and spatial coding is crucial for reaching further understanding of the processes contributing to spatial coding. Also, Quinn (1990) indicated that many experiments in the literature that show interfering effects have arguably confounded their interpretation by failing to control CE effects. The CE has not been in the forefront of experimentation into the WM model, nevertheless it is reckoned to be the system which controls attention. Where interfering tasks require attention, it is unclear to what extent the tasks themselves cause interference or whether the interference is caused by the attention to the tasks. While appropriate control experiments go some way towards countering this effect, Quinn argues, uncertainty in WM research will continue while the relationship between the CE and each one of its subordinates remain largely unexplored.

The primary visuo-spatial task used in this experiment was the SB matrix task. This task was presented either verbally or visually as in Experiments 1-a&c in both of which recall was verbal. Three concurrent movement tasks were used to examine their interference effects on verbal and visual *encoding* of the Brooks task. These movement tasks were simple tapping, spatial tapping, and rhythmic tapping. A hypothesis was tested for each secondary task.

Secondary tasks:

1) Simple tapping:

Simple tapping in this experiment involved repeated tapping with the stylus of a single metal plate in response to a regular auditory signal. Simple tapping has been used as a secondary task by many researchers for various purposes. For instance, Vallar & Baddeley (1982) used it as a control task which should not make specific demands on articulatory processes. Logie & Salway (1990) indicated that repeated tapping of the same plate constituted a secondary task to investigate the effects of response production at a preset rate. They used this task to gauge whether any disruptive effects of the *spatial suppression task* (spatial tapping) could just be attributed to a requirement to generate a repeated motor response. Quinn & Ralston (1986) and Smyth & Pelky (1992) have used this task as a control movement task which should not make specific demands on spatial resources, but nevertheless provides some load.

According to Smyth & Pendleton (1989) spatial WM (VSSP) may be best thought of as a system involving movement to targets in space. It is designed, if it exist at all, to deal with the planning of movement to locations in space. They suggested that other sorts of movement such as configurational movement may involve a different WM subsystem. Since simple tapping does not involve movements to targets in space, it should not occupy the sensory buffer (VSSP) and thus should not interfere with concurrent visuo-spatial processing. Simple tapping was used in this experiment as a control task for generating a repeated motor response. It is thus hypothesised that a simple tapping movement which requires no attention and involves no movement to targets in space will not interfere with verbal or visual encoding the Brooks Matrix task.

2) Spatial tapping:

Spatial tapping involved sequential tapping of 4 spatially distributed targets in response to a regular auditory signal. This task was devised by Farmer et al (1986) as a spatial analogue of the articulatory suppression technique that requires continuous visuo-spatial activity with minimal demands upon CE resources. Farmer et al asked their subjects to use a stylus to contact each of 4 metal plates (positioned in a square arrangement) in turn, working continuously and as rapidly as possible in a clockwise direction. Both speed and the sequence of contacts were recorded by a computer. Farmer et al argued that this task places minimal demands upon CE resources and interferes with spatial reasoning in WM preventing the solution of spatial problems, but not verbal problems. They indicated that performance disruption by concurrent spatial tapping is indicative of the shared need for specialised visuo-spatial WM functions. Many researchers (e.g. Logie & Salway, 1990; Salway, 1990; Smyth et al, 1988; Smyth & Pendleton, 1989; Smyth & Pelky, 1992) have used this task as a spatial suppression task that has a large motor component and thus should utilise the resources of the VSSP. Smyth & Pendleton (1989) found this task to interfere with recall of a series of positions in space and concluded that it is primarily a spatial task that utilises some of the resources involved in general spatial processing, although it is clearly motor at lower levels in the output system. It has been suggested that motor processes are involved when we attempt to process and maintain visuo-spatial information (Hitch, 1984). Quinn & Ralston (1986) and Logie (1986) have implicated motor activity in the functioning of the VSSP and pointed out the importance of movement in spatial coding. Smyth & Pendleton argued that movement which is implicated in the functioning of the VSSP is chiefly spatial in character and that the VSSP itself may derive from the need to maintain locations in external space in order to direct action towards them.

Since this task has been implicated to have large spatial and motor components, it is predicted to disrupt the concurrent workings of the VSSP. It is thus hypothesised that this task will interfere with both verbal and visual encoding of the Brooks Matrix task. The Brooks task is assumed to rely on the VSSP for encoding the digits relative to one another within the matrix and forming a mental image (path) representing the digits to aid recall. Smyth et al (1988) indicated that motor processes are implicated in maintaining such a spatial path or sequence. Spatial tapping is also assumed to occupy the VSSP and thus, when combined with the encoding of the Brooks task, it should interfere with the spatial representation of the matrix task. It would be interesting to find out if this task will interfere with visual encoding as well as verbal encoding of the Brooks task. Farmer et al (1986) pointed out that identification of the range of conditions under which spatial suppression occurs may represent a fruitful method of exploring the characteristics of the VSSP.

3) Rhythmic tapping:

Rhythmic tapping involved tapping a single metal plate in response to a rhythmic (variable) auditory signal. Simple and spatial tapping have been widely used as secondary tasks (e.g. Farmer et al, 1986; Smyth & Pelky, 1992) and their memory and processing demands appear to be relatively well known. Rhythmic tapping, on the other hand, has not been used as a secondary task involving the CE, at least in the available literature. Some studies which attempted to examine the role of the CE used various other secondary tasks. For instance, random generation of single letters or series of digits has been used (e.g. Baddeley, 1986; Logie & Salway, 1990; Salway, 1990) as a task that involves CE processing, but the relationship between this task and the functioning of the CE is uncertain and Logie & Salway (1990) argued that its use as a secondary task is clearly not straightforward. Backward counting has also been used as a CE secondary task (e.g. Vallar & Baddeley, 1982; Smyth & Pelky, 1992) and is indicated to be a task that makes heavy demands on CE resources.

Another task used in the literature as a CE secondary task is reaction time to tones (Baddeley et al, 1986). This task is somewhat similar to the rhythmic tapping task used in this experiment. In this task the subject is presented with a series of tones from a loudspeaker. The task involved pressing a footswitch as rapidly as possible after commencement of the tone. The inter-tone interval was randomly varied in order to ensure that the subject was unable to use the rhythmic cues associated with a regular rate. A form of rhythmic tapping has been used by Saito (1993, 1994) who examined whether complex rhythmic finger tapping would disrupt the running of speech motor programs and thus abolish the phonological similarity effect. The rhythmic tapping task used by Saito required the subject to tap a button of Microsoft mouse with the index finger, in synchronisation with a sequence of a rhythm that a personal computer auditorily indicated (tone frequency, 440 Hz). This rhythm pattern was composed of 5 notes with 2 syncopations per a bar; a bar had 4 beats (a beat=400 msec).

It was hypothesised that a rhythmic movement task which requires attention and judgement but requires no sequential movement to targets in space will interfere with verbal, but not with visual, encoding of the Brooks Matrix task. Rhythmic movement is predicted to interfere with the CE processes associated with verbally encoding this task, but it is predicted not to interfere with direct visual encoding of this task. Rhythmic tapping used in this experiment has the advantage of being comparable to the simple tapping task except in one element which is the variable rate of tapping which is supposed to require concentration, decision making and other executive processes. As explained in chapter 1, many of the CE functions are attentional and the CE is basically concerned with the integration of information and the attentional control of action. In fact, Baddeley (1986) has equated the CE with the SAS (Norman & Shallice, 1986) which is assumed to involve conscious control and is called for in various situations including those requiring decision making or in which the next response is not obvious.

In summary, spatial tapping is predicted to interfere with encoding the Brooks task regardless of encoding modality. This interference should not occur with simple tapping which does not have a large motor (spatial) component and, hence should not occupy the sensory buffer. Smyth et al (1988) pointed out that movement per se can not be important for the VSSP. A differential interference is predicted to come from rhythmic tapping by disrupting verbal, but not visual, encoding of the matrix task. Rhythmic tapping should not interfere with the visuo-spatial representation since this sort of movement is not directed towards targets in space and is comparable to simple tapping except in regard to the amount of attention, judgement, and timing which this rhythmic movement requires. If an interference occurs by rhythmic tapping, it will be due to this attentional and control element.

These predictions are based on the above process model of the verbal and visual encoding of the Brooks task. This model assumes that verbal presentation requires heavy CE involvement to generate images from LTM and switch attention between the verbal input and image generation before registering the task material onto the sensory buffer (VSSP). In contrast, with visual presentation the CE involvement is minimised since there is no switching of attention to search for information from which to generate images and the task materials are rather registered directly onto the buffer. Figure 4.2 shows a summary of these assumed processes:

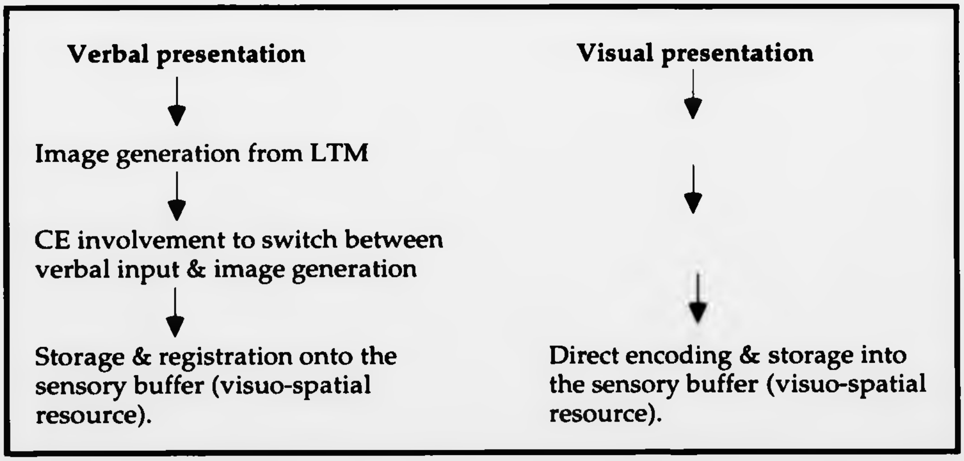


Figure 4.2. A summary of the processes assumed to be associated with aural & visual encoding of the Brooks matrix task.

With this process model in mind, this experiment examined some questions such as: Will concurrent movement interfere with performance of the Brooks task when it is presented visually as much as when it is presented aurally?, Does movement interfere with image generation (CE) or with the visuo-spatial representation?, Why does movement to targets in space interfere? Is it because it uses a common spatial WM resource or just because it loads CE resources?. It is assumed that if the Brooks Matrix task occupies a spatial WM resource, a concurrent spatial movement should occupy the same resource and interfere with memory for that task. If spatial movement disrupts performance equally under both verbal and visual encoding then both tasks use a visuo-spatial WM resource. If it disrupts image generation (verbal presentation) but not direct encoding (visual presentation), then it only interferes with CE resources.

Subsequent to testing, subjects were asked to answer the VMIQ (see chapter 2 & Appendix 1.1). Subjects' ratings on the VMIQ were correlated to their performance on the Brooks task to examine whether vividness of movement imagery correlates with performance.

4.2.2. Method

1) Material & equipment

The primary visuo-spatial task was the Brooks Matrix task. This task was presented to subjects in two forms, verbal and visual presentation. Three movement tasks were used as the interference tasks during the *encoding* stage. These three tasks were: simple tapping, spatial tapping and rhythmic tapping. The following is a description of the primary and secondary tasks:

The Brooks Matrix task:

Verbal presentation: The same material used in Experiment 1-a were used. A 4x4 square matrix (22x22cm) was used. The second cell on the second row was marked with a cross as the starting square. Subjects were shown this matrix at the beginning and then asked to visualise it. While visualising the matrix, subjects were presented with a sequence of 8 sentences describing a path around the matrix. The path always began from the starting square and involved placing the digits 1-8 in their successively designated squares of the 'mental' matrix. Each sequence of 8 sentences always began from the starting square and dealt with the digits in ascending numerical order. The first sentence of each sequence was always the same. The only way in which different sequences (sets of 8 sentences) differed was the sequence of transitions (up-down, right-left) from one square to another. These sequences were designed so that two digits were never assigned to the same square and that a digit was never placed outside the matrix.

This experiment involved 4 interference conditions: control, simple tapping, spatial tapping and rhythmic tapping. For each condition, 4 sequences (tests) were used, 1 for practice and 3 for the experimental trials. Therefore, 16 sequences of 8 sentences were needed. The 8 sequences used in Experiment 1-a were used and 8 more sequences were developed (see Appendix 3.1). The same procedure and guidelines used in constructing the sequences in Experiment 1-a were followed in constructing these additional 8 sequences (tests).

The 16 sequences were recorded using a male voice on an audiocassette for use with all subjects. Presentation of the sentences was paced during recording by a Birkbeck Timer at the rate of 1 sentence per 2.5 seconds. Each sequence thus took about 20 seconds to present. During testing, the sequences (tests) were played out from a tape-recorder. Another tape-recorder was used to record subjects' responses since they responded verbally to each test by repeating the 8 sentences. Responses to the 12 experimental trials were also simultaneously hand-recorded by the experimenter on A4 sheets, each containing 12 small 4x4 matrices, by writing down the digits in the squares as they are assigned (recalled) by the subject.

Visual presentation: The same 16 Brooks sequences used for verbal presentation were used as the test material for visual presentation. The task material were presented visually using the same equipment used in Experiment 1-c. In Experiment 1-c, the first 8 sequences of sentences were prepared on slides and presented to subjects visually using a slide projector. The new 8 sequences of sentences were also transformed into sequences of slides following the same procedure used to transform the SB sequences into sequences of slides in Experiment 1-c.

Thus, 16 sequences of 8 slides were used for visual presentation. Each slide showed only 1 digit in its designated square. The slides were displayed on a portable screen using a slide-projector. The projector was connected to a Birkbeck Timer in order to automatically pace the rate of presentation. Each slide was presented at the rate of 1 slide per 2.5 seconds. Two Bell push switches with open contacts were connected to the Timer in order to operate it, and thus operate the projector, remotely. As in Experiment 1-c, subjects responded verbally to this visual presentation of the task by describing the locations of the digits using sentences identical to those used in the verbal presentation. Responses to the testing trials were tape-recorded for subsequent analysis. Responses were also simultaneously hand-recorded by the experimenter as with verbal presentation.

Secondary Tasks:

Three secondary movement tasks were used. In the dual task conditions, subjects were required to carry out one of these tasks *during* the verbal or visual presentation of the Brooks task. These tasks were:

a) Spatial Tapping: This task is based on the task devised by Farmer et al (1986), and subsequently used by others (Salway, 1990; Smyth et al, 1988; Smyth & Pendleton, 1989; Smyth & Pelky, 1992). In this experiment, the apparatus for this task consisted of 4 metal plates (each 70x70mm) positioned in a square arrangement on a 23.5x38cm horizontal board, with 25mm separation between adjacent plates (see Appendix 3.2). A metal-tipped stylus was also used for tapping the 4 metal plates. Farmer et al indicate that the dimensions and spacing of the metal plates were designed to eliminate the need for precise aiming of the stylus. A Rustrak 4-Channel Event Recorder, made by BRD Electronics, was also used. This machine uses a roll of thermal paper for recording responses which, when the machine is operated, runs at the speed of about 7.5mm per second. The stylus and the 4-Channel Event Recorder were electrically connected to the apparatus (board) so that if it is operated, whenever the stylus touched any of the 4 plates, the touch is immediately recorded on the thermal paper by the corresponding channel in the Event Recorder. Each of the plates is connected to a corresponding channel so that plate 1 is connected to channel 1, plate 2 is connected to channel 2, and so on. Each channel has a corresponding space on the roll of the thermal paper which enabled recording the tapping of each plate. The stylus was used in tapping the 4 plates. The regularity of tapping and the inter-tap intervals were recorded by the Event Recorder. A hard board screen was mounted on 2 retort stands and put in front of the subject in such a way as to prevent him (her) from seeing the tapping board.

The subjects' task was to tap round the 4 plates in turn in a clockwise direction whenever they heard an auditory signal. This signal was a 'simple beep' recorded on an audiocassette from a MacintoshPlus computer using the application HyperCard (HC). The experimenter programmed HC to emit and repeat the *beeps* at a regular rate of 1 *beep* per second for the desired length. The HC script is shown in Appendix 3.3. These signals were then played out during testing from a tape-recorder. Thus, in this spatial tapping task the subject tapped each of the 4 plates in its turn in a clockwise direction at the regular rate of 1 plate per second.

b) Simple Tapping: The same apparatus used for the spatial tapping task was used for simple tapping. Subjects were required to tap only on one metal plate which was the right one of the bottom row. Subjects were asked to tap on this single plate every time they heard the signal which was at the rate of one signal per second as in spatial tapping.

c) Rhythmic Tapping: This task was the same as the simple tapping task with one important modification. Instead of tapping on the metal plate at the regular and repetitive interval of one second, subjects tapped in time to a repeated pattern of auditory signals which were at variable intervals. To obtain these rhythmic signals, HC was again used and programmed to emit 'simple beeps' at the following temporal intervals: *(wait 25 ticks, beep; wait 60 ticks, beep; wait 100 ticks, beep; wait 55 ticks, beep)*. A tick in HC equals 1/60 of a second. Thus, the intervals between tones were 0.41, 1.0, 1.67, 0.92 seconds. HC was programmed to emit and repeat this sequence of rhythmic signals for the desired length of time. The HC script is shown in Appendix 3.3.

This sequence was prepared while taking into consideration that the number of signals, and thus the number of tapping movements made in each interference condition, should be equal. These rhythmic signals were then recorded from the computer on an audiocassette and used with all subjects in this condition. Thus, unlike the regular simple tapping, rhythmic tapping involved variable intervals between auditory signals which should require the subject's attention to anticipate each signal and make judgements regarding when to tap and when to pause.

2) Design

A 2 (modality of presentation) x 4 (movement interference conditions) within subjects repeated measures design was used. The 4 interference conditions were: no interference, spatial tapping, simple tapping, and rhythmic tapping. Subjects were tested individually and each was tested on the Brooks task under both verbal and visual presentation. The subject was tested during 2 different sessions. In the first session he (she) was given the task under one form of presentation and in the second session he (she) was given the task under the other form of presentation. The order of these two forms of presentation was counterbalanced across subjects so that half the subjects were tested using verbal presentation first followed by visual presentation and the other half of subjects were tested in the reverse order. This was accomplished by testing the first 4 subjects using verbal presentation first and then testing the next 4 subjects using visual presentation first and so forth. In the dual-task conditions, subjects were asked to carry out 1 of the 3 tapping tasks during the *encoding stage* of the Brooks task. Recall was immediate after presentation and involved no tapping movement.

The order of administering the 4 interference conditions was balanced across subjects according to a Latin square design. There were 16 tests for each form of presentation: 16 sequences of 8 sentences for verbal presentation and 16 identical sequences of 8 slides for visual presentation. These 16 tests were divided into 4 blocks of 4 tests. In each block, the first test was used as a practice trial on the current interference condition and the remaining 3 tests were used for the 3 experimental trials. The first block of tests was always used for the first interference condition to be given, the second block was always used for the second interference condition to be given, and so on. The order of administering the interference conditions was counterbalanced across subjects. This procedure was intended to ensure that each interference condition appeared an equal number of times under each block of tests, ensuring that any peculiarities of a particular block of tests were not associated with a particular movement interference condition (Quinn, 1988b).

3) Subjects

Sixteen participants (9 males, 7 females) were recruited from students attending undergraduate and postgraduate courses at Warwick University and took part in this experiment. Each was offered a fee of £3 and their age ranged from 19-28. None had participated in any of the previous experiments. Each subject was tested in two separate sessions with an interval of no less than 2 hours and no more than 24 hours. During each session, the subject was tested using one form of presentation and each session lasted for about 45-50 minutes.

4) Experimental set-up & procedure:

The subject was seated at a rectangular table. The experimenter sat at the left end of the table which is located on the left hand side of the subject. In front of the experimenter, a 30cm-high x 45cm-wide wooden stand was placed on the tabletop in order to hide the test material from the subject's sight. In front of the subject, the 4 metal plates-tapping apparatus was placed on the table along with the hard-board screen mounted on 2 retort stands so as to prevent the subject from seeing the 4 metal plates when tapping. Three tape-recorders were placed near the experimenter. The first was for playing the verbal Brooks tests during the verbal presentation condition, the second was to record subjects' responses, and the third was to play the auditory signals during the tapping conditions. These signals were either regular for the simple and spatial tapping conditions, or variable for the rhythmic tapping condition. The 4-Channel Event Recorder was placed within the reach of the experimenter. Behind the subject, there was a special stand on which the slide-projector was mounted in such a way that, when the projector was operated, the projection light passed over the head of the subject and each slide was projected on the middle of the portable screen which was placed approximately 2 metres away facing the subject. This projector was used to present the task in the visual presentation condition. The two Bell push switches, that operate the Birkbeck timer and thus operate the projector, were placed within the reach of the experimenter. During testing, the light in the room was reduced to allow clear projection of the matrix during visual presentation.

Photographs showing the experimental set-ups for verbal and visual presentation, with the subject encoding the Brooks task whilst tapping in time to the auditory signal, are provided in Appendix 3.2.

Testing Procedure:

Testing during verbal and visual presentation of the Brooks Matrix took the following procedure:

a) For verbal presentation:

The subject was initially introduced to the Brooks task. They were shown the 4x4 matrix with the starting square marked and told that they would listen to a set of 8 sentences that describe the locations of the digits 1-8 in relation to one another within the matrix. They were told that the 8 sentences were of the sort *'In the starting square put a 1, In the next square up (down, to the left, or to the right) put a 2'* and so on. Subjects were shown how the sentences related to the matrix and were informed that the first digit was always placed in the same starting square while the other digits were successively placed relative to one another within the squares of the matrix. They were also informed that during testing the matrix will not be present and that they are supposed to rely on forming an image of the digits on a path around the matrix. It was explained that the only way in which tests, sets of 8 sentences, differed was the sequence of transitions (up, down, right, left) from one square to another.

Subjects were instructed to repeat the 8 sentences word by word after the last sentence had been presented. They were instructed to attempt to remember the sentences, which describe the locations of the digits relative to one another within the matrix, by forming a mental image of the digits in relation to each other within the squares of matrix. They were told that this image could then be used to reconstruct the sentences at recall. They were also informed that there was no limit on response time and that their responses were being tape-recorded. In the first tapping condition to be given, subjects were also introduced to the tapping apparatus. In each movement interference condition, subjects were given detailed instructions and practice on how to tap and they were allowed to practise each tapping task on its own prior to using it as a secondary task.

Practice Procedure:

There were 4 conditions which were administered in a counterbalanced order according to a Latin square design. For the first condition to be given 2 practice trials were given. The first was on the Brooks task on its own and the second was on the current interference condition. Practice took the following procedure: the first test of the first block of tests was always used for these two practice trials. In the first practice trial, the subject was presented with the 4x4 matrix with the starting square marked and asked to listen to the sequence of sentences and to repeat verbatim the 8 sentences after the last sentence had been presented and the matrix had been removed. After this trial, the matrix was removed for the rest of the experimental session.

Then a second practice trial (a repeat of the same test) was given without the matrix being present at input. In this second practice trial, if the first condition to be given involved movement interference, the subject was asked to carry out the required type of tapping during the encoding process. In the remaining 3 conditions to be given, only 1 practice trial was given for each condition with no matrix present at input. The first test of each of the remaining 3 blocks of tests was always used for that practice trial. In all 3 *tapping* conditions, after subjects were introduced to the tapping task, they were allowed to practise tapping on its own for about 2 minutes or until they indicated readiness to begin the dual-task trials.

Testing Steps:

There were four conditions. In the control condition no interference task was carried out whilst each of the other 3 dual-task conditions involved carrying out a concurrent movement task. Testing in these 4 conditions took the following procedure:

1) Control condition:

If this condition was to be administered first, subjects were first introduced to the Brooks task as outlined in the testing procedure. The first test of the current block of tests was used for practice following the practice procedure outlined above. After the practice period, 3 testing trials were administered using the remaining 3 tests in the current block. No diagram was present during input or output and subjects were not asked to carry out any secondary task.

2) Simple tapping condition:

If this dual-task condition was to be given first, subjects were first introduced to the Brooks task and given a practice trial on that task as explained above. Subjects were then introduced to the tapping task and given some training on how to tap as explained in the practice procedure. Then they were informed that during presentation of the 8 sentences they were required to tap using the stylus on the indicated single metal plate every time they heard the regular auditory signal. Subjects were asked to start tapping prior to presentation of the Brooks task and to continue tapping throughout. They were instructed and encouraged to tap in time with the signal and to stop tapping after the last sentence had been presented and the signal had been stopped. It was pointed out that there would be no tapping during recall. Thus, the secondary task was performed during *encoding* only.

The first test of the current block of tests was used for the practice period as outlined in the practice procedure. After this practice period, 3 experimental trials were given using the remaining 3 tests in the current block. Before the Brooks sentences were played out, the experimenter played the regular auditory signal from the other tape-recorder for the subject to commence tapping. The signal was stopped immediately after the last sentence had been presented. In this condition, and in the other two tapping conditions, the hard-board screen, mounted on two retort stands in front of the subject, was adjusted so as to prevent the subject from seeing the tapping device during tapping.

3) Spatial tapping condition:

The same procedure and steps used in the simple tapping condition were used with one exception regarding the tapping instructions. Subjects in this condition, which involved movement to targets in space, were instructed to tap during presentation, round the 4 metal plates in turn in a clockwise direction using the stylus. They were instructed to tap each plate in its turn every time they heard the auditory signal which was at the rate of 1 signal per second. They were asked to stop tapping after the last sentence had been presented and the signal had been stopped. Subjects were encouraged to hit the plates accurately in the indicated sequence every time they heard the signal.

4) Rhythmic tapping condition:

The same procedure and steps used in the simple tapping condition were used with a slight modification concerning the tapping instructions. Subjects were instructed to tap on the indicated single metal plate whenever they heard the auditory signal. As explained above, this signal was different from the signal in the above two conditions in regard to its rhythm. Subjects were informed that the intervals between the signals were variable and that they must try to keep up the tapping with these signals.

b) For visual presentation:

Each subject performed the Brooks Matrix task in both verbal and visual presentation forms. The order of administering these 2 forms was counterbalanced across subjects so that half subjects were given verbal presentation first whilst the other half were given visual presentation first. The same procedure and steps used with verbal presentation were used in presenting the task visually but with some modification to suit visual presentation:

Subjects were shown a 4x4 matrix with the starting square marked and initially introduced to the task. As in Experiment 1-c, they were informed that they were required to watch 8 consecutive displays of the matrix on the portable screen by 8 slides that show the locations of each of the digits 1-8 in relation to each other within the squares of the matrix. It was indicated that the first digit was always placed in the same starting square and that the rest of the digits were successively placed relative to one another within the matrix. It was pointed out that each slide displayed only one digit at a time in its designated square. Subjects were shown how the displays related to the matrix and were informed that the only way in which tests, sets of 8 slides, differed was the sequence of transitions (up, down, left, right) from one square to another.

Subjects were instructed to recall the locations of the digits verbally after the last slide had been presented. They were instructed to describe the locations of the digits within the squares of the matrix using sentences with the following structure:

In the starting square put a 1.
In the next square up (down, to the left, or to the right) put a 2.
In the next square up (down, to the left, or to the right) put a 3.
........and so forth until the location of last digit (8) was described.

Recall was thus verbal as with verbal presentation. The same recall and imagery instructions which were used for verbal presentation were used here. Subjects were informed to attempt to remember the 8 displays by forming a mental image of the digits relative to one another within the squares of the matrix. They were told that they could then use that image at recall to reconstruct the digits and put them in the appropriate sentences.

In the first tapping condition to be given, each subject was introduced to the tapping device. The practice and testing steps were the same as those used with verbal presentation. There were 16 tests each consisting of 8 slides. These tests were exactly the same as the tests used in verbal presentation except that sentences were replaced by slides. The 16 tests were divided into 4 blocks of 4 tests to be used for the 4 interference conditions exactly as was done with verbal presentation. The 4 interference conditions were administered according to a Latin square design. The same experimental procedures used in administering the 4 conditions under verbal presentation were exactly used with slight modifications to fit the change from verbal into visual presentation. In both testing sessions (verbal and visual presentation), the detailed introduction to the Brooks task took place at the first condition to be administered.

Thus, in all conditions, the *tests* were either played out from a tape-recorder or displayed by a slide-projector at the rate of 1 sentence (slide) per 2.5 seconds. Subjects' responses were simultaneously hand-recorded by the experimenter as explained in the material section. In addition, responses were tape-recorded to double-check the accuracy of the hand recording. Specific sets of instructions were prepared for each condition under each form of presentation and were used with all subjects (see Appendix 3.4). As in the Brooks procedure, no specific knowledge of results was given to subjects but they were periodically encouraged about their performance. No limit was imposed on response time.

4.2.3. Results

Performance was measured by the number of sentences subjects were able to recall or construct correctly. Errors were counted for each subject in each interference condition. An error refers to any sentence that was recalled (or constructed) incorrectly in terms of its spatial adjective or in terms of the identity of the digit involved. In each trial, 8 sentences had to be recalled. The first involved no spatial adjective and was always the same and thus involved no errors. There were therefore 7 possible errors in each trial and since each subject was given 3 experimental trials in each interference condition, there were 21 possible errors per subject in each condition. Table 4.a shows the mean percentage of error in each condition under each form of presentation, and Figure 4.3 illustrates these data.

Presentation	No interference	Simple tapping	Spatial tapping	Rhythmic tapping
Verbal	10.14 (13.24)	18.14 (25.90)	25.29 (13.33)	25.29 (16.38)
Visual	4.76 (9.05)	8.62 (12.67)	10.43 (11.14)	10.43 (8.90)

Table 4.a. Mean percentage of error in each interference condition under each form of presentation of the Brooks Matrix. (SDs are shown in parentheses; N=16)

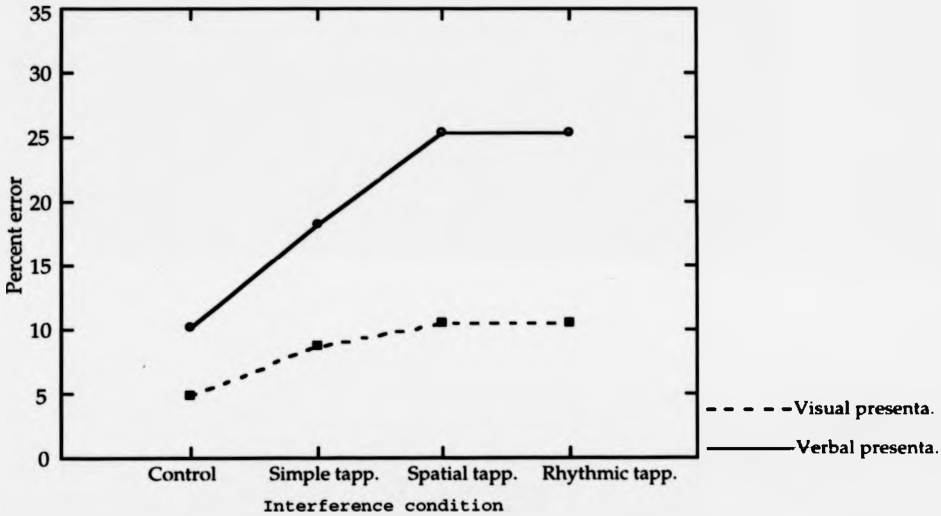


Figure 4.3. An illustration of the mean percentage of error in each interfrence condition under each presentation modality of the Brooks matrix.

The above data were analysed using a 2(presentation modality) x 4(interference condition) within subjects repeated measures ANOVA. Order of presentation of the primary task was included as an independent grouping factor. The analysis showed a highly significant main effect of form of presentation [$F(1,14)=30.03$, $P=0.00$]. Verbal presentation led to significantly more errors at recall. There was a significant interaction between form of presentation and administration order [$F(1,14)=7.31$, $P=0.02$]. Verbal presentation was significantly harder when it was given first. Order had no significant main effect [$F(1,14)=0.08$, $P=0.78$] and it did not interact with interference condition [$F(3,42)=0.08$, $P=0.97$].

There was a significant main effect of interference condition [F(3,42)=3.40, P=0.03]. There was some indication that the sphericity assumption was not strictly true, a Greenhouse-Geisser correction still yielded a significant difference (epsilon=0.68, P=0.047). There was no significant interaction between form of presentation of the task and type of interference condition [F(3,42)=1.25, P=0.30]. As can be seen in the above figure, there was no differential effect of any of the secondary tasks across the two forms of presentation. The predicted interaction did not occur. Performance of the Brooks task under both forms of presentation was similarly disrupted by the secondary tasks. Since there was no significant interaction, post hoc pairwise comparisons among the means were conducted on the conditions under both forms of presentation combined. Benferroni-adjusted tests were used by dividing the significance level (0.05) by the number of comparisons (in this case 6). This post hoc analysis showed that spatial and rhythmic tapping (conditions 3&4) significantly differed from the no interference condition. No other comparisons were significant.

In addition to this combined main analysis, separate one way ANOVAs were carried out on the verbal and visual presentation data with the 4 interference conditions as the within subjects repeated measures variable. The results of these subsidiary analyses were as follows:

For verbal presentation: The analysis showed a significant main effect of interference condition [F(3,45)=3.25, P=0.03]. There was some indication that the sphericity assumption was not strictly true, a Greenhouse-Geisser correction still yielded a significant difference (epsilon=0.68, P=0.05). Post hoc Tukey tests showed that the only significant differences between means were between conditions 1, control, and 3, spatial tapping, (P=0.049); and conditions 1, control, and 4, rhythmic tapping, (P=0.049). All other pairwise mean comparisons were nonsignificant.

For visual presentation: The analysis showed no significant main effect of interference condition [F(3,45)=1.30, P=0.29]. There was an indication that the sphericity assumption was accurate, a Greenhouse-Geisser correction yielded a nonsignificant difference (epsilon=0.77, P=0.29).

As indicated above, the main analysis showed that order of administration interacted with presentation modality of the Brooks task. Order of administering the two forms of the task was counterbalanced so that half subjects took the 'aural' Brooks first whereas the other half took the 'visual' Brooks first. Figure 4.4 shows the mean percentage of error when taking either form of the task first or second.

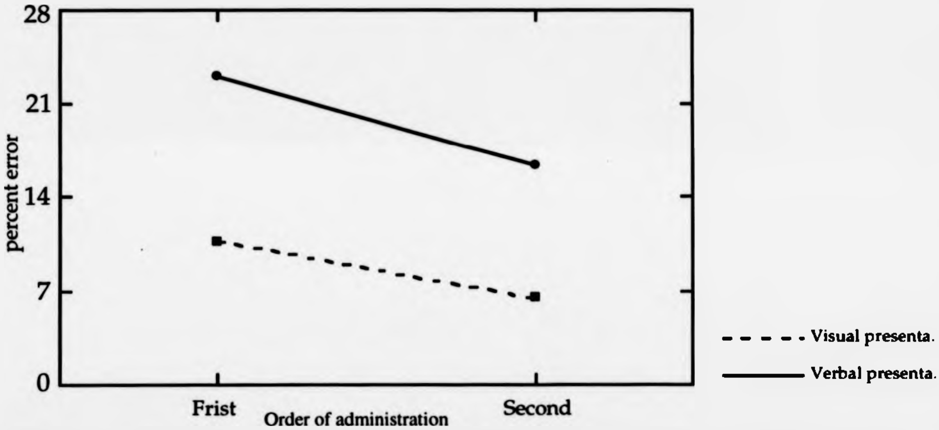


Figure 4.4. Mean percentage of error made when either form of the task was administered first or second.

It is clear from the above figure that subjects performed better when taking either task-form second which indicates insignificant practice effect. But as the ANOVA showed, there was a significant interaction between administration order and task-form which indicates that the 'verbal' form is significantly harder when it was given first. When verbal presentation was preceded by visual presentation performance with the former improved. Also, when visual presentation was preceded by verbal presentation performance with the former improved but to a less significant extent. This implies that encoding the Brooks task visually first provides more effective training and familiarisation with the task than does encoding it verbally first. The *presence* of the task material at encoding appears to provide more effective learning and practice.

An analysis of the SP effect was carried out on the data of both verbal and visual presentation in order to find out the nature of the SP curves and whether more errors at the beginning or at the end of each set of 8 sentences. Errors made at each of the 8 serial positions under each form of presentation were counted. 16 subjects were tested and each was given 12 testing trials under each presentation modality, thus each position had 192 chances of being error. Figure 4.5 shows the mean percentage of error at each SP under both presentation modalities.

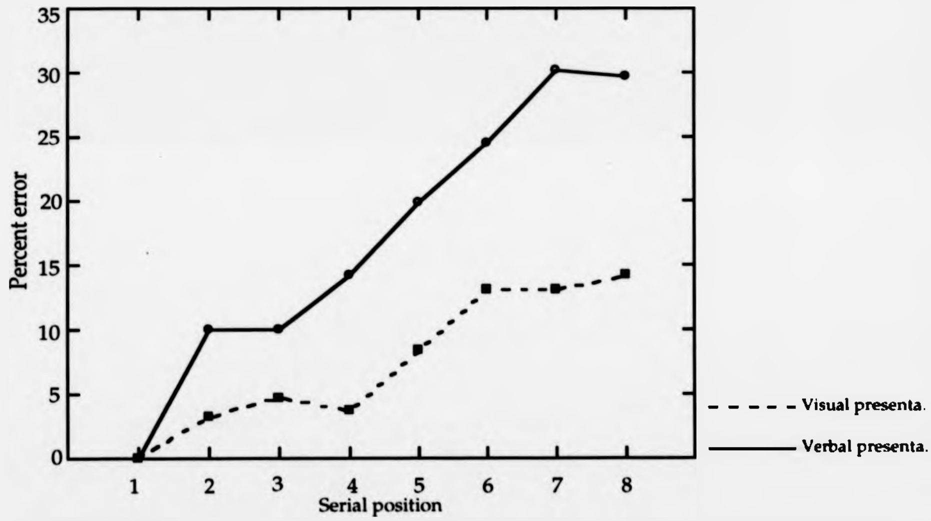


Figure 4.5. The SP curves for verbal and visual presentation of the Brooks matrix task.

The two curves shown in figure 4.5 appear to be parallel with the error rate increasing approximately linearly with SP. As usual, no errors were made at position 1 since it involved no spatial adjective and was always the same sentence (in the starting square put a 1). Therefore, position 1 was excluded from the SP statistical analysis. A 2(presentation modality) x 7(positions) within subjects repeated measures ANOVA was performed on this SP data with presentation modality as the independent factor and serial positions 2-8 as the repeated measures variable. This analysis showed a highly significant main effect of presentation modality [F(1,15)=21.14, P=0.00]. Significantly more errors were made under aural presentation. There was a highly significant main effect of SP [F(6,90)=17.21, P=0.00]. Significantly more errors were made at some positions than at others. Under both presentation modalities, more errors were made at the most recent items than at the primary items. The interaction between form of presentation and SP just failed to reach statistical significance [F(6,90)=2.02, P=0.07]. The two curves appear to be parallel.

Subjects' ratings on the VMIQ were correlated to their performance on the verbally and the visually presented Brooks Matrix task. A Spearman correlation test showed no significant correlation between ratings on the VMIQ and performance on the verbally presented task (rho=0.18, p>.05) and the visually presented task (rho=-0.37, p>.05). An attempt to interpret this result is provided in section 4.4. The correlation matrix also showed that there was a relatively high positive correlation between subjects' performance on the 'verbal' Brooks and the 'visual' Brooks task although this correlation failed to reach statistical significance (rho=0.30, p>.05).

4.2.4. Discussion

The purpose of this experiment was to examine the cognitive processes involved in performance of the Brooks Matrix task when it was presented in verbal and visual modalities and to examine some hypotheses regarding movement interference with the processing of this task. As explained in chapter 2, numerous studies (e.g. Baddeley et al, 1975b; Idzikowski et al, 1983; Quinn, 1988a) found that concurrent movement interferes with the encoding of this task. It is less clear, however, whether the interference is due to the two tasks sharing a common visuo-spatial WM resource or whether the interference is due to the involvement of CE processes which may be required by the active encoding of this memory task and the concurrent performance of a secondary task.

It was assumed that verbal encoding of the Brooks Matrix requires heavy CE involvement to switch between the current input (Brooks sentences) and the generation of images from LTM. This experiment attempted to minimise the CE involvement by visually presenting the task. It was assumed that verbal encoding relies on both the CE and the VSSP whereas visual encoding relies mainly on the VSSP. To test this assumption, 3 secondary tasks were used to examine their interference effects on performance of the Brooks under each form of presentation. Simple tapping was used as a control movement task that should not place demands on the VSSP or the CE and thus should not interfere. Spatial tapping was used as a movement task that should occupy the VSSP and hence should interfere with performance under both verbal and visual presentation. Finally, rhythmic tapping was used as a differential CE task that should interfere only with performance of the Brooks Matrix when it was verbally presented. Rhythmic tapping was assumed to require heavy CE involvement and thus should selectively interfere by disrupting performance under verbal, but not visual, encoding. Visual encoding of the Brooks was assumed by the process model to require minimum CE involvement. Unlike verbal encoding, visual encoding demands no switching between verbal input and memory input (image generation), instead the task is directly encoded from the visual display.

Results showed that this predicted interaction between presentation modality and type of secondary task did not occur. The lowest numbers of errors were made at the control condition then errors insignificantly increased for simple tapping whilst the highest numbers of errors were made at both spatial and rhythmic tapping conditions. This pattern occurred equally for both forms of presentation. In general, the size of effect that an experiment will detect is limited statistically by the power of that experiment. Thus, a nonsignificant effect might in principle be significant if a more powerful experiment, involving a larger sample, were to be carried out. A detailed interpretation of this lack of an interaction will be discussed in the next section.

In general, performance under visual presentation of Brooks task was superior to performance under verbal presentation. The overall mean percentage of error under visual presentation was 8.56 whereas it was 19.71 under verbal presentation. This result replicates the results of Experiment (I). When asked, all subjects indicated that the task was much easier when it was presented visually. Some subjects were asked about the reasons for this and typical replies were *"because with verbal presentation I have to make all the images in my head"* or *"with visual presentation I don't need to do a lot of imagination, or visualisation"*. Subjects were also asked to describe the strategy they relied on to recall the task material. All subjects indicated relying on their visual imagery to recall the digits and their locations. The image was often described as a shape, a line or a pattern, sometimes within a grid or 'a little box'. This image (shape) was then used or *'followed'* to describe the locations of the digits. Subjects attributed any recall difficulty to the image being lost or to the *shape* having faded.

Subsequent to testing, each subject was asked to rate the difficulty of each interference condition relative to the other conditions. For visual presentation, the majority of subjects rated the control condition as the easiest followed by simple tapping with very few subjects making the opposite rating. About 70% of subjects rated the spatial tapping condition as the hardest whilst the rest rated rhythmic tapping as the hardest because it required concentration. For verbal presentation, the majority of subjects rated the control condition as the easiest followed by simple tapping with very few subjects making the opposite rating. But, unlike visual presentation, about 85% of subjects rated rhythmic tapping as the hardest whilst the rest rated spatial tapping as hardest. The difficulty of rhythmic tapping was attributed to its demand for concentration and decision making.

As can be seen in table 4.a, each interference task led to poorer performance in comparison to the control condition. Under both presentation forms, simple tapping which was predicted not to interfere, led to insignificantly more errors relative to the control condition. This lack of an effect by simple tapping could be taken as indicating that any effect of spatial or rhythmic tapping is not simply due to generating a repeated motor response. Also, there is evidence that repeated tapping of a single target disrupts the production of fast, highly controlled motor responses (Logie et al, 1989). The lack of such a disruption suggests that the motor output control required to make a secondary response was not an important component of the primary task.

As predicted, spatial tapping led to significantly larger disruption under both verbal and visual presentation although this was clearer with verbal presentation. Similarly, rhythmic tapping which was predicted by the process model to interfere only with verbal encoding, led to significant disruption although this was clearer with verbal encoding. The disruption by spatial tapping could be taken as indicating that this task shares mental resources with the encoding of the primary task. In this case, these are visuo-spatial resources. Similarly, the disruption by rhythmic tapping could be taken as indicating that this task shares mental resources with the encoding of the memory task. In this case, these are general purpose (CE) resources. This implies that encoding of the matrix task, whether it is verbal or visual, utilises or relies on visuo-spatial as well as CE resources in WM.

However, by looking at the visual presentation data, it seems that there is relatively low variation. Presenting the Brooks task visually appears to make the task easy and there is a possibility of a ceiling effect (this issue is discussed in a next section). Therefore, it may be less clear whether and to what extent these small levels of errors should count as specific interference effects or as 'cost of concurrence'. Cost of concurrence is a common theme in multiple resource theory (Wickens, 1984). This theory refers to a number of specialised resources that may act independently of one another or in concert to meet task demands. According to the concept of multiple resource (Navon, 1987; Wickens, 1984), there are several specialised resources on which an operator may draw, with assignment of a particular resource determined by the nature of the task. Thus, the concurrent performance of two dissimilar tasks is facilitated, since each will require a different resource. Similar tasks will require similar resources, thereby leading to inefficient performance when such tasks are concurrent. Also, according to this theory, in dual tasks there is commonly a 'cost of concurrence' (Navon & Gopher, 1979), or a general processing load resulting from the necessity to coordinate the activities of two or more resources. Navon & Gopher suggested that in such cases there may also be a processing overhead or a 'cost of concurrence'; that is, when two tasks are performed together the overall load may be greater than the sum of the loads imposed by each task performed singly. This extra demand to coordinate the activities of two or more tasks may reflect the operation of an 'executive time-sharer' (Hunt & Lansman, 1981; McLeod, 1977).

Thus, cost of concurrence may result from the increased load in monitoring two tasks or as Navon & Gopher put it "the process of organising, coordinating, scheduling and allocating resources may require resources in itself" (1979, P.225). Baddeley (1986) suggested that one meaning of the term 'CE' implies some type of supervisor or scheduler but the other meaning is more of a central rag-bag covering processes which are not specific to the posited subsystems. Logie et al (1990) considered errors as large as 15 and 20 per cent found with secondary tasks to mean that specialised subsystems are not involved but that executive monitoring functions which are related to the 'cost of concurrence' are involved. Larger errors were considered as implicating specific subsystems. Smyth & Pelky (1992) pointed out that this Logie et al's estimate may be too high. Shallice et al (1985), for instance, indicated that two tasks can be taken as using different processing structures if the performance decrement when they are combined is less than 10 per cent. The general argument, thus, appears to be that the smaller of two sets of error data reflects the costs of dual task performance, whereas larger errors reflect specific competition for a common resource.

Serial position effect: Regarding the SP analysis, the obtained curves (figure 4.5) for both verbal and visual presentation are similar. There was a primacy effect and a 'negative' recency effect. The highest error rates were at the most recent items. Unlike free-recall experiments in which SP curves tend to show primacy and recency effects, recall in this experiment was constrained. Recall was verbal under both forms of presentation. With verbal presentation, subjects recalled the sentences by repeating them verbatim, and with visual presentation they described the locations of the digits by constructing sentences identical to those used with verbal presentation. This method of recall demanded that the items be recalled in the order in which they were presented. This could be responsible for the 'negative' recency effect. Subjects reported that during encoding they used their visual imagery to build up a shape (pattern) representing the digits within the matrix. This *shape* was then used at retrieval to read off the digits and describe their locations. Subjects usually report difficulty in recalling the last few items because they tend to lose the end of the *shape* or as some subjects indicate *"the end of the shape just fades away"*. This could explain the good performance in recalling the primary items and the large increase in error rate at the last few positions. Another possible interpretation of this result is that the VSSP comprises a limited capacity store that could retain a limited number (5 or 6) of items. Thus, during encoding this store gets 'filled up' by the time the last few items are presented. Some studies which used serial-recall reached a similar result. For instance, Morris (1989) found that more errors were made at the most recent items when subjects had to recall the items in the order in which they were presented.

In the verbal presentation condition, the lowest error rates were at the first few items with error rate increasing approximately linearly with SP. The SP curve for verbal presentation in this experiment is quite similar to the SP curve obtained in Experiment 1-a. Both experiments used the same presentation and recall modalities. In the visual presentation condition, a relatively similar curve occurred in which error rate increased approximately linearly with SP. Again, this curve is similar to the curve obtained in Experiment 1-c which had the same presentation and recall modalities. In short, recalling the items in the order in which they had been presented leads to a 'negative' recency effect.

Summary:

The predicted interaction between interference condition and presentation modality of the Brooks Matrix did not occur. Rhythmic tapping was predicted to have a selective effect by only disrupting performance under verbal presentation. Some factors might have led to this result and to the lack of large interference effects by spatial tapping. These factors are:

1) Presenting the Brooks task visually may have made it easy which did not allow for a greater variation in the data and may subsequently led to a ceiling effect. Variance among subjects in the visual presentation data was low. Table 4.a shows the SDs for the 4 conditions under both presentation modalities. Thus, the lack of greater interference effects observed under visual presentation could be due to the low error rate (although not exactly a ceiling effect). At higher error rates, the interference effects might become more apparent. One method for making the task harder to avoid a possible ceiling effect is to use a 5x5 square matrix instead of the standard 4x4 matrix and probably to use 9 instead of 8 digits.

In the original Brooks task (Brooks, 1967) a 4x4 square matrix is used and subjects are presented with 8 sentences describing the locations of the digits 1-8. The sentences describe movements (up, down, left, or right) around the matrix and the subject is instructed to remember the sequence of movements by visualising them in the *imaginal* matrix. This original form has been repeatedly used as a primary visuo-spatial task in investigating the VSSP (e.g. Baddeley et al, 1975b; Baddeley & Lieberman, 1980). Logie et al (1990) used this form as a secondary visuo-spatial task but they used only 6 sentences and no explanation was provided for this modification. Some other researchers have used a slightly modified version of the Brooks Matrix as their primary task (Quinn & Ralston, 1986; Quinn 1988a&b, 1990, 1991; Salway, 1990). In this version, a 5x5 matrix was used and, in addition, 9 sentences were mostly used which describe the locations of 9 digits (or letters, Salway, 1990). Unfortunately, these studies provided no explanation for using this variant. It is not clear why they used a 5x5, instead of the standard 4x4, matrix.

It is expected that using a 5x5 matrix with 9 digits would make the Brooks task more difficult since this will allow the construction of more difficult sequences (tests). With a 5x5 matrix there will be a total of 25 squares which will allow for the assignment of the digits to a wider variety of squares that are not very close to each other. A 5x5 matrix will lead to using a wider variety of spatial adjectives and thus the probability of sequentially designating squares within one row or one column will be reduced. In this experiment, the experimenter noticed that some tests were easier than others. For instance, tests 11 and 16 had the lowest error rates under both forms of presentation. These 2 tests were characterised by more squares being sequentially designated within certain rows and columns and, thus by less variation in the use of spatial adjectives. In short, to overcome a possible ceiling effect under visual presentation, it is suggested that using a 5x5 matrix with 9 digits would make the task harder and hence remove this possibility.

2) A second factor that might have led to the predicted interaction not occurring is the slow rate of tapping. Subjects tapped on the plates in response to an auditory signal which was at the rate of 1 signal per second in the simple and spatial tapping conditions and at a variable rate in the rhythmic tapping condition. This variable rate was organised in such a way that if the total number of taps made in each trial was averaged, a tap was being made every 1 second. This ensured that an equal number of tapping movements was made in each condition.

Previous researchers who used simple and spatial tapping as secondary tasks (e.g. Farmer et al, 1986; Smyth et al, 1988; Smyth & Pelky, 1992) asked their subjects to tap as quickly as possible. In contrast, in this experiment subjects tapped at a constrained rate of 1 tap per second. Mary Smyth (personal communication) indicated that this rate is too slow. A faster rate of tapping will result in more movements being made and thus may lead to stronger interference effects and more variation in the data. However, Salway (1990) used spatial tapping which was paced at the rate of 1 tap per second and yet it led to interference effects with encoding of the Brooks Matrix task.

3) The third, and probably most important, factor is that subjects did not perform to the criterion in the rhythmic tapping condition. This factor could be responsible for the absence of the predicted interaction between presentation modality and interference condition. The experimenter observed that in this condition, particularly under verbal presentation, subjects tended to concentrate more on the primary task and to ignore the instruction to tap in time with the *rhythmic* signal. Subjects did not keep up the tapping with the signal and they ignored some signals whilst concentrating on encoding the Brooks sentences. This resulted in irregular tapping that does not correspond to the signal. Some subjects ignored some signals despite being instructed not to do so whilst others started off each trial with good concurrent tapping then tapping started to slow down and be incompatible with the signal. However, a few subjects performed to the criterion during some trials in this condition. In the simple and spatial tapping conditions in which tapping was at a regular rate, subjects found it easier to perform to the criterion and tapping was generally regular and in time with the signal. To provide some evidence for these observations, the tapping records were analysed as follows:

Tapping data:

Tapping performance was recorded using a 4-Channel Event Recorder. The tapping records for each condition were analysed in order to examine whether subjects' tapping conformed to the auditory signals. The procedure and results for each tapping condition were as follows:

a) Simple tapping:

To find out to what extent subjects' tapping in this condition conformed to the standard rate of tapping, a standard sequence of tapping intervals in millimetre (mm) was obtained by measuring the intervals between 'expected' taps on the thermal paper. Subjects were expected to tap on the single plate in time with the regular signal which was at the rate of 1 signal per second. This rate was found to correspond to about 7.5mm on the thermal paper. Since subjects were expected to tap on the target every 1 second, then there should be a tapping mark on the thermal paper at the fixed interval of about 7.5mm.

Each of the 16 subjects was given 3 trials in each condition. Thus, the total number of trials in this condition was 48 trials under each form of presentation. In each trial, tapping performance on the thermal paper was measured in mm. The *obtained* tapping intervals in mm were then compared to the *expected* tapping intervals. A paired samples t-test was performed on the tapping data for each trial in order to find out whether it differed from the *expected* set of tapping intervals (fixed intervals of 7.5mm). The results were as follows:

For aural presentation: A paired samples t-test was performed on each of the 48 trials comparing the *obtained* sequence to the *expected* tapping sequence. The results of these t-tests showed that out of the 48 trials, 13 trials significantly differed from the standard tapping rate ($P<0.05$) whereas the remaining 35 trials did not significantly differ ($P>0.05$). Thus, in 35 trials there was strict compliance with the tapping instructions.

For visual presentation: The same procedure was used. The *obtained* tapping intervals were compared to the *expected* tapping rate (constant intervals of 7.5mm). The results of the paired samples t-tests showed that out of the 48 trials, only 4 trials significantly differed from the expected tapping rate ($P<0.05$) whereas the remaining 44 trials did not significantly differ ($P>0.05$). Thus, in 44 trials subjects complied with the standard tapping rate.

In general, under both presentation modalities subjects mostly tapped in a way that is similar to the standard simple tapping rate although there seems to be more compliance under visual presentation. Under verbal presentation, 13 trials differed significantly from the standard rate which indicates that subjects in these trials did not fully comply. In 2 of these trials, tapping intervals were shorter than the standard intervals indicating that the subject was tapping at a faster rate which resulted in making more taps. In the remaining 11 trials tapping intervals were generally longer than standard intervals indicating that these subjects did not respond to some signals or that their response time was slow. In such cases, fewer tapping movements were made relative to the expected tapping sequence.

Under visual presentation, 4 out of the 48 trials significantly differed from the standard rate. In 3 of these trials, made by one subject, that subject was tapping at a faster rate which resulted in more tapping movements being made. In the fourth trial, the tapping intervals were much longer than the expected intervals indicating that the subject did not respond to some signals which resulted in fewer taps being made. Under both visual and verbal presentation, in the trials that did not significantly differ from the standard rate, the tapping intervals were very close to the expected intervals of 7.5mm. Thus, under both presentation modalities, subjects' overall simple tapping was regular and largely in time to the signal.

b) Spatial tapping:

To find out how regularly and accurately subjects tapped round the 4 targets, the *spatial taps* on the thermal paper were checked and counted for each trial under both presentation modalities. Subjects were instructed to tap round the 4 targets in turn in a clockwise direction at the rate of 1 target per second and to try to hit the targets accurately in this sequence. Each tap was recorded, in its designated space on the thermal paper, by the corresponding channel in the Event Recorder. When this Recorder is operated, the thermal paper moves at the speed of about 7.5mm per second. Therefore, it is possible to examine compliance with the spatial tapping instructions by examining the tapping records to find out if subjects missed any of the 4 targets in every tapping sequence (a sequence of 4 taps round the 4 plates).

For visual presentation, the tapping records showed that in 32, out of the 48, trials subjects did not miss any of the tapping targets whereas they missed some targets in the remaining 16 trials. For verbal presentation, in 36 trials subjects did not miss any of the targets whereas they missed some targets in the remaining 12 trials. To examine the significance of these missed targets (errors), performance in each of these trials was compared to the *expected* sequence which is 1 tap in its designated space on the thermal paper every 1 second. Paired samples t-tests showed that for visual presentation only 3 trials significantly differed from the expected sequence ($P<.05$). For verbal presentation, the t-tests showed also that only 3 trials differed from the expected sequence ($P<.05$). Thus, subjects' overall spatial tapping, under both input modalities, appears to be reasonably regular and conforming to the criterion of tapping round the 4 targets in turn in a clockwise direction in time to the signal. However, some subjects in some trials missed some targets and hit the board instead. In such cases, subjects were reminded of the instructions.

c) Rhythmic tapping:

The rhythmic tapping records for both presentation modalities showed that tapping was generally not conforming to the rhythmic signal. There also appears to be some differences in this regard between verbal and visual presentation. Rhythmic tapping under verbal presentation was much more irregular. Some subjects ignored some signals whereas others tapped in a way that was not corresponding to the rhythmic tapping rate but rather was similar to the simple tapping rate. The records showed that subjects made fewer rhythmic movements under verbal presentation of the Brooks task. In some trials, intervals between rhythmic taps were much longer than the expected intervals. Under visual presentation, occasionally similar patterns occurred but to a much less extent. In some cases, tapping tended to correspond to the signal at the beginning of each trial and then it became slower and inconsistent towards the end. In addition, under both forms of presentation some subjects tapped better than others.

To examine to what extent subjects' tapping correlated to the standard tapping rhythm, a standard tapping sequence was obtained by measuring (in mm) the expected tapping rate on the thermal paper. That is, the rhythmic intervals were converted into their corresponding intervals on the thermal paper. The expected temporal rhythmic intervals (0.41, 1.0, 1.67, 0.92 seconds) were found to correspond to a sequence of 4-8-11-7mm on the thermal paper. In each trial, this rhythm is repeated resulting in the following expected sequence of intervals on the tapping records: 4-8-11-7-4-8-11-7-and so on. Then, tapping in each trial under both presentation forms was measured in mm on the thermal paper in order to examine the correlation between the obtained and the expected intervals. The analysis of the obtained data was as follows:

<u>For verbal presentation:</u> 16 subjects were tested and each was given 3 trials in each interference condition. Thus, in this condition there were 48 trials. Tapping performance in each trial was measured as intervals in mm. The obtained tapping intervals for each trial were then correlated to the expected sequence of rhythmic intervals. Pearson correlation tests showed that only 22, out of 48, trials correlated significantly and positively with the expected intervals ($p<.05$) whereas the remaining 26 trials did not significantly correlate with the expected intervals ($p>.05$). The correlation coefficients for all of the 48 trials were averaged. The resulting average correlation coefficient was $r=0.43$.

<u>For visual presentation:</u> The same procedure was followed. The Pearson correlation tests showed that 31, out of the 48, trials correlated positively and significantly with the expected rhythmic intervals ($p<.05$) whereas the remaining 17 trials did not significantly correlate ($p>.05$). The correlation coefficients for all of the 48 trials were averaged. The resulting average was $r=0.55$.

Thus, with verbal, as opposed to visual, presentation subjects' tapping was less conforming to the standard rhythmic rate. The average correlation coefficient under verbal input was $r=0.43$ whereas it was $r=0.55$ under visual input. To examine the significance of this difference, the correlation coefficients for the 48 trials under verbal input were compared to their counterparts under visual input. A paired samples t-test showed a significant difference ($t=2.16$, $df=47$, $p=0.04$). In short, *aural* encoding of the Brooks Matrix seems to have interfered with rhythmic tapping performance more than did *visual* encoding. Subjects' overall rhythmic tapping, under both presentation modalities, did not generally conform to the expected rate and this could be an important factor behind the lack of the predicted interaction between presentation modality and interference condition.

Conclusion:

This experiment examined movement interference in WM specifically whether concurrent movement interferes with active visuo-spatial processing because both tasks share a common visuo-spatial WM resource or whether interference is only due to the involvement of the hypothetical CE. Verbally encoding the Brooks task was assumed to require heavy CE involvement to switch between the verbal instructions (sentences) and the generation of images from LTM. Visually encoding the Brooks task was assumed to minimise the CE involvement since the materials are presumably directly encoded into the VSSP. To examine the proposed process model, the task was administered to subjects in both aural and visual modalities. The effects of 3 movement tasks were examined. It was hypothesised that the effects of simple and spatial tapping tasks would be equal across the two forms of presentation whereas the differential effect should result from a rhythmic tapping task. Rhythmic tapping was expected to demand attention, concentration and other executive processes and thus should interfere only with aurally encoding the Brooks Matrix. This predicted interaction was not found. Some factors may have led to this result which include: subjects did not perform to the rhythmic tapping criterion, the tapping rate in all conditions was too slow, and a ceiling effect may have occurred due to the easiness of visually encoding the Brooks task.

To examine these assumptions, some subsidiary experiments could be conducted to clarify each one of these factors. A follow-up experiment might test the issue of tapping being too slow by using a faster rate (e.g. 1 tap per 0.5 second). This will result in an increase in the number of movements made during each trial and might lead to more interference particularly with spatial tapping. Another subsidiary study might examine the issue of subjects not rhythmically tapping to the criterion by finding a way to make them comply with the tapping instructions. Another issue to be investigated is the possibility that with visual presentation, the Brooks task has become too easy to allow for sufficient variation in the data. To overcome this, it is suggested that a 5x5 matrix with 9 digits could be used instead of the standard 4x4 matrix with 8 digits. Overcoming the above flaws and making these modifications may provide an experimental task and design that would allow for a precise assessment of the role of movement in visual STM and of the relationship between the VSSP and the CE components of WM. The next subsidiary experiment examined the most important factor believed to be behind the lack of the predicted interaction between interference condition and presentation modality. That is, subjects in the rhythmic tapping condition did not comply with the tapping instructions and thus did not perform to the criterion.

4.3. Experiment 2-B: A Subsidiary Experiment.

4.3.1. Introduction:

This subsidiary experiment was conducted in light of the results of Experiment 2-a which mainly investigated the relationship between the hypothetical CE component of WM and one of its proposed subordinates, the VSSP, and whether a dissociation can be established between these two systems. In particular, Experiment 2-a examined the cognitive processes believed to be involved in performance of the Brooks Matrix when it was presented aurally or visually, and investigated the kind of movement that interferes with these two kinds of encoding. The effects of various movement tasks on the encoding of this task were examined in an attempt to investigate whether concurrent movement interferes because both tasks share a common visuo-spatial WM resource or whether interference is due to CE loading. According to the proposed process model, aural encoding of the Brooks Matrix requires the generation of visual images (of the matrix) from LTM and thus requires heavy CE involvement in order to switch attention between the incoming aural input and image generation. On the other hand, visual encoding demands no generation of images during input since the matrix is present on the screen for direct encoding. With visual presentation there is no translation of verbal input into visual images, and switching of attention may occur but there is no longer a need to switch attention in order to search for information from which to generate images. It was assumed that *aural* encoding involves both the CE and VSSP whereas *visual* encoding mainly involves the VSSP.

Experiment 2-a tested the above assumptions by examining the effects of three movement tasks on verbal and visual encoding of the Brooks Matrix. These were simple, spatial and rhythmic tapping. It was hypothesised that simple tapping should not interfere with performance of the Brooks task under both presentation modalities. Simple tapping does not involve movement to targets in space and thus should not occupy the VSSP. Also, this tapping is regular and repetitive and does not require considerable attention and concentration and, hence should not require heavy CE involvement. Spatial tapping, which is assumed to be a spatial suppression task, was predicted to interfere with performance of the Brooks under both presentation modalities. The Brooks task is supposed to be a visuo-spatial task that utilises the VSSP for its processing whether it is presented aurally or visually. Thus, spatial tapping or suppression should interfere with the concurrent processing of such visuo-spatial material regardless of presentation modality.

The selective interference was predicted to come from a rhythmic tapping task that was assumed to require attention and concentration and hence high CE involvement. Aurally encoding the Brooks task was also assumed by the process model to demand high CE involvement to switch attention between external verbal input and internal memory input. Thus, rhythmic tapping was predicted to interfere with aural encoding (image generation) but not with direct visual encoding which was assumed to require minimum CE involvement.

Results of Experiment 2-a failed to show this predicted interaction between presentation modality and movement interference condition. The pattern of interference effects produced by the 3 secondary tasks was similar for both aural and visual presentation. Spatial and rhythmic tapping significantly disrupted performance on the Brooks Matrix task under both forms of presentation. The predicted selective interference of rhythmic tapping did not occur. Some factors were assumed to have led to such an unexpected result. One factor was that with visual presentation, the Brooks task may have become too easy. To overcome this, a 5x5 matrix with 9 digits may be used in order to make the task harder and thus abolish any possibility of a ceiling effect. A second factor was that the tapping rate was too slow. A faster rate should lead to more movements being made and thus to stronger interference effects.

A third and important factor was that with rhythmic tapping, subjects did not comply with the instructions to tap in time to the signal. They, particularly under aural presentation, seem to have concentrated more on the primary task and paid less attention to the rhythmic tapping task. The tapping records showed that in some trials the tapping intervals didn't match the expected intervals indicating that subjects did not respond to some rhythmic signals and were rather concentrating on encoding the primary visuo-spatial task. This pattern occurred more with aural, than with visual, presentation. In dual-task paradigms, it is expected that there will be mutual or reciprocal interference between the primary and the secondary task.

That is, usually there is a cost of concurrence as performing each task alone results in fewer errors than performing the two tasks concurrently. However, in Experiment 2-a the experimenter observed that subjects tended to take the memory task much more seriously than the tapping task. Hence, they paid more attention to the Brooks task and occasionally ignored some auditory signals. This particularly occurred with rhythmic tapping which was supposed to demand more concentration and effort. This non-compliance with the rhythmic tapping instructions might have been a significant factor behind the lack of the predicted interaction between presentation modality and movement interference condition.

This experiment was devoted to examining this third factor of non-compliance with the tapping instructions. It was predicted that if subjects attempted to treat the primary and secondary tasks equally by not concentrating on one more than the other, then rhythmic tapping may have a selective interference effect by disrupting performance with verbal, but not with visual, presentation. This prediction was based on the proposed process model of the Brooks task.

Experiment 2-a had four interference conditions: control, simple tapping, spatial tapping, and rhythmic tapping. It had the overall aim of attempting to tease apart the VSSP and the CE components of WM by showing that a CE task (rhythmic tapping) interferes with a visuo-spatial task that requires image generation and heavy CE involvement, but not with the same task when these processes were no longer required. If the VSSP functions independently from the CE, then rhythmic tapping should have no significant effect on performance of a visuo-spatial task that requires minimum CE involvement. A spatial tapping (suppression) task was predicted to disrupt performance of the Brooks Matrix, which presumably relies on the VSSP, whether it is presented aurally or visually.

This experiment replicated two interference conditions of Experiment 2-a, namely spatial and rhythmic tapping, using a smaller sample of subjects. The only difference introduced in this follow-up experiment was related to the tapping tasks. New, stringent tapping instructions were used which emphasised the dual-task nature of the experiment and thus the importance of performing the two tasks simultaneously and treating them equally by not concentrating on one more than the other. Such procedure had been used by some studies in the literature. For instance, Naveh-Benjamin (1987) in a dual-task study of coding of spatial information explicitly instructed his subjects to pay equal attention to each of the two concurrent tasks. Also, Saito (1994) instructed his subjects before the experimental session that both the memory and the tapping tasks were important. This modification in the introduction and instructions of the tapping tasks will be explained in the procedure section.

The Brooks Matrix task was presented both aurally and visually. Subjects carried out two concurrent movement tasks. The first was spatial tapping which was predicted to interfere with the Brooks task whether it was aurally or visually encoded. The second was rhythmic (CE) tapping which was predicted to interfere with aural, but not visual, encoding. Visually encoding the Brooks Matrix was assumed to require no image generation and thus no switching of attention to search for information from which to generate images. Such encoding should require minimum CE involvement. If the VSSP functions independently from the CE, then the CE task should not interfere with visual encoding.

4.3.2. Method

Material & equipment:

The same material and equipment used in Experiment 2-a were used. The Brooks task was presented in both verbal and visual modalities. Unlike Experiment 2-a which had 4 movement interference conditions, this experiment had only 2 conditions which were spatial and rhythmic tapping. Therefore, only 9 tests (sequences of 8 sentences or slides) were used. The first 9 tests of the two sets of 16 tests which were used for aural and visual presentation in Experiment 2-a were used. Under each presentation modality, these 9 tests were used for practice and testing trials. All other material, equipment and procedures for presenting the Brooks task aurally and visually and for carrying out the two secondary tapping tasks were the same as those used in Experiment 2-a. The only change this experiment introduced was related to the introduction and instructions of the tapping tasks which was intended to ensure more compliance with the tapping instructions. This change is explained in the procedure section.

Subjects

Eight subjects (5 males, 3 females) were recruited from undergraduate & postgraduate students at Warwick University and took part in this experiment. Each was offered a fee of £3 and was tested in two separate sessions with an interval of no less than 2 hours and no more than 24 hours. During each session, the subject was tested using one form of presentation. Each session lasted for about 30-40 minutes. Subjects' age ranged from 20-32 and none had participated in any of the previous experiments.

Design:

A 2(presentation modality) x 2(interference condition) within subjects repeated measures design was used. Subjects were tested individually and each was tested in 2 separate sessions. In the first session, the subject was given the Brooks task under one form of presentation and in the second session he (she) was given the task under the other form of presentation. The order of administering the two forms of presentation was counterbalanced across subjects so that half were tested using verbal presentation first whereas the other half were tested using visual presentation first. This was accomplished by testing the first two subjects using verbal presentation first and then testing the next two subjects using visual presentation first and so forth. The order of administering the two interference conditions was also counterbalanced across subjects so that half were given spatial tapping first whereas the other half were given rhythmic tapping first. This was accomplished by giving the first subject the spatial tapping condition first and then giving the next subject the rhythmic tapping condition first and so on.

The first 9 tests of the two sets of 16 tests which were used for both forms of presentation in Experiment 2-a were used. Thus, for verbal presentation there were 9 tests (sequences of 8 sentences) and for visual presentation there were 9 identical tests (sequence of 8 slides). The first test of each was used for the practice trial on the Brooks Matrix task during the introduction of this task to the subject. The other 8 tests were divided into 2 blocks of 4 tests. In each block, the first test was used as a practice trial on the current interference condition and the remaining 3 tests were used for the 3 experimental trials. As in Experiment 2-a, the first block of tests was always used for the first interference condition to be given and the second block was always used for the second condition to be given. The order of administering the interference conditions was counterbalanced across subjects. This procedure was intended to ensure that each interference condition appeared an equal number of times under each block of tests ensuring that any peculiarities of a particular block of tests were not associated with a particular interference condition.

Experimental set-up

The same experimental set-up used in Experiment 2-a was used in this experiment.

Testing procedure:

Testing in this experiment followed the same steps and procedures that were used in Experiment 2-a. The steps followed in verbally and visually presenting the Brooks Matrix in Experiment 2-a were followed. This included the introduction procedure to the Brooks task under both presentation modalities, the recall and imagery instructions and so on. The only difference is that in this experiment there were only two, rather than four, interference conditions.

The only modification introduced in this experiment was related to the tapping tasks. This experiment attempted to overcome the issue of non-compliance with the tapping instructions particularly in the rhythmic tapping condition. Therefore, modified and stringent tapping instructions were used which emphasised the dual-task nature of the experiment and hence the importance of simultaneously performing and treating the two concurrent tasks equally.

The experimenter attempted to introduce the tapping tasks not as 'secondary tasks' but as tasks that are as important to perform as the Brooks task. It was stressed to subjects that good performance means performing the two tasks simultaneously and thus they must not concentrate on one task and neglect the other. It was indicated that the purpose of the experiment was to have subjects perform two tasks concurrently and that they are required to do their best on both tasks and not just on one. It was also pointed out to each subject that their tapping performance would be recorded by the Event Recorder, and also that their responses to the Brooks task would be tape-recorded. The purpose of these modifications in the introduction and instructions of the tapping tasks was to attempt to make subjects take the tapping tasks as seriously as they take the memory task. With no such elaborate and stringent instructions, subjects in Experiment 2-a tended to take the memory task much more seriously than the tapping tasks. In this experiment, there were two movement interference conditions, spatial and rhythmic tapping. The tapping instructions and testing procedures for these two conditions were as follows:

1) Spatial tapping

If this condition was to be administered first, subjects were first introduced to the experiment. They were told that it was a dual-task experiment which required subjects to carry out two tasks simultaneously. The experimenter attempted to introduce the two tasks not as primary and secondary tasks but as two equally important tasks that should be performed concurrently. Subjects were then introduced to the Brooks task either in its aural or visual modality using the same procedure used in Experiment 2-a. The subject was then given a practice trial on the Brooks task alone using the first test of the 9 tests. Then, subjects were introduced to the tapping task and given some training on how to tap. They were made familiar with tapping device and with how their tapping performance was being recorded by the Event Recorder. Subjects were allowed to practise the tapping task for about 2 minutes or until they indicated readiness to start the dual-task trials. Then they were given a practice trial on the dual-task using the first test of the first block of 4 tests followed by 3 testing trials using the remaining 3 tests in that block. If this condition was to be administered second then a slightly different procedure was used as will be explained in the rhythmic tapping section.

Subjects were informed that during presentation of the 8 sentences (or slides) they were required to tap, using the stylus, round the 4 metal plates in turn in a clockwise direction. Unlike Experiment 2-a, some modified or new statements were included in the instructions (see Appendix 3.4). These were: "You *must tap each plate in its turn every time you hear the auditory signal (beep). You must try not to miss any beep. Your tapping will be recorded by this machine. Also, always remember that your task is to perform the two tasks simultaneously and you must treat the tasks equally by not concentrating on one task more than the other"*. Then, as in Experiment 2-a, it was explained to subjects that they should stop tapping after the last sentence had been presented (the last slide had been displayed) and that there was no tapping during recall. Periodically throughout testing subjects were reminded of these instructions to perform and treat the two tasks equally. All other instructions and procedures were the same as those used in Experiment 2-a.

2) Rhythmic Tapping

If this condition was to be administered first, subjects were first introduced to the experiment and informed about its dual-task nature as explained in the spatial tapping section. But if either condition was to be given second, then the subject was only introduced to the current tapping condition and given some training on the tapping task as explained above. Then the subject was given a practice trial on the dual-task using the first test of the second block of tests followed by 3 experimental trials using the remaining 3 tests in that block.

Subjects were informed that *during* presentation of the 8 sentences (slides) they were required to tap, using the stylus, on the indicated single metal plate. Unlike Experiment 2-a, some modified or new instructions were included: (see Appendix 3.4). These were: "you *must tap on this plate every time you hear the auditory signal (beep). The intervals between the signals are variable and you must keep up the tapping with the signals. You must try not to miss any beep. Your tapping will be recorded by this machine. Also, always remember that your task is to perform the two tasks simultaneously and you must treat the two tasks equally by not concentrating on one task more than the other".* Subjects were informed that they should stop tapping after the last sentence (slide) had been presented and that there was no tapping during recall. Periodically throughout testing subjects were reminded of these instructions particularly the instruction to perform and treat the two tasks equally. All other instructions and procedures were the same as those used in Experiment 2-a.

Thus, there was more emphasis on the dual-task nature of the experiment during the initial introduction of this experiment to subjects. An attempt was made to convey the crucial importance of performing the two tasks concurrently and treating them equally. In addition, more specific and stringent instructions were used and subjects were occasionally reminded of these instructions throughout testing in order to ensure appropriate compliance. All other testing procedures for aural and visual presentation of the Brooks task were the same as those used in Experiment 2-a. Each subject answered the VMIQ subsequent to testing.

4.3.3. Results

Errors were counted for each subject in each interference condition. An error refers to any sentence that was recalled (or constructed) incorrectly in terms of its spatial adjective or in terms of the identity of the digit involved. In each trial, 8 sentences had to be recalled. The first sentence involved no spatial adjective and was always the same and thus involved no errors. There were therefore 7 possible errors in each trial and since each subject was given 3 trials in each interference condition, there were 21 possible errors per subject in each condition. Table 4.b shows the mean percentage of error in each condition under each form of presentation, and Figure 4.6 illustrates these data.

Presentation modality	Spatial tapping	Rhythmic tapping
Verbal	38.69 (23.39)	38.10 (21.14)
Visual	16.67 (12.73)	19.64 (12.58)

Table 4.b. Mean percentage of error in each interference condition under each form of presentation of the Brooks Matrix. (SDs are shown in parentheses; N=8)

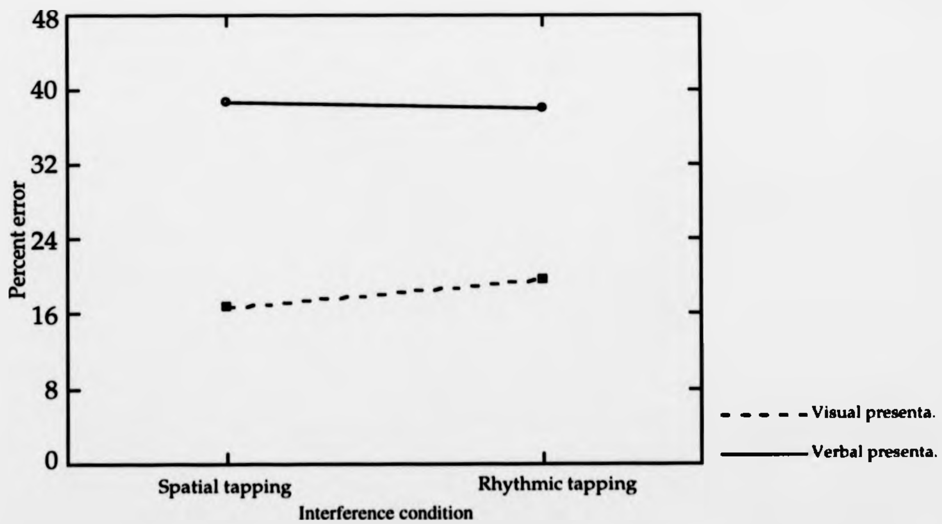


Figure 4.6. The mean percentage of error in each interfrence condition under each presentation modality of the Brooks matrix.

The above data were analysed using a 2(presentation modality) x 2(interference condition) within subjects repeated measures ANOVA. Order of administering the two forms of presentation was included as an independent grouping factor. The analysis showed a significant main effect of presentation modality [F(1,6)=11.88, p=0.01]. Verbal presentation of the Brooks Matrix led to significantly more errors. There was no significant interaction between the two forms of presentation and their order of administration [F(1,6)=0.04, p=0.85]. Unlike Experiment 2-a, verbal presentation is not significantly harder when it was given first. Order had no significant effect [F(1,6)=0.00, p=0.95) and it did not interact with condition [F(1,6)=0.00, p=1.00).

The ANOVA also showed no significant main effect of interference condition [F(1,6)=0.05, p=0.83]. The spatial and rhythmic tapping tasks interfered equally with performance of the Brooks Matrix under both presentation modalities. There was no significant interaction between presentation modality and interference condition [F(1,6)=0.11, p=0.75]. The two tapping tasks equally disrupted performance regardless of presentation modality. Thus, the predicted interaction did not occur as rhythmic tapping disrupted both verbal and visual encoding and thus had no selective interference effect.

As indicated above, order of administering the two forms of presentation had no significant effect and did not interact with presentation modality. Order of administering the two forms of presentation was counterbalanced so that half subjects were given the 'aural' Brooks first whereas the other half were given the 'visual' Brooks first. Figure 4.7 shows the mean percentage of errors made by subjects when taking either form of the task first or second:

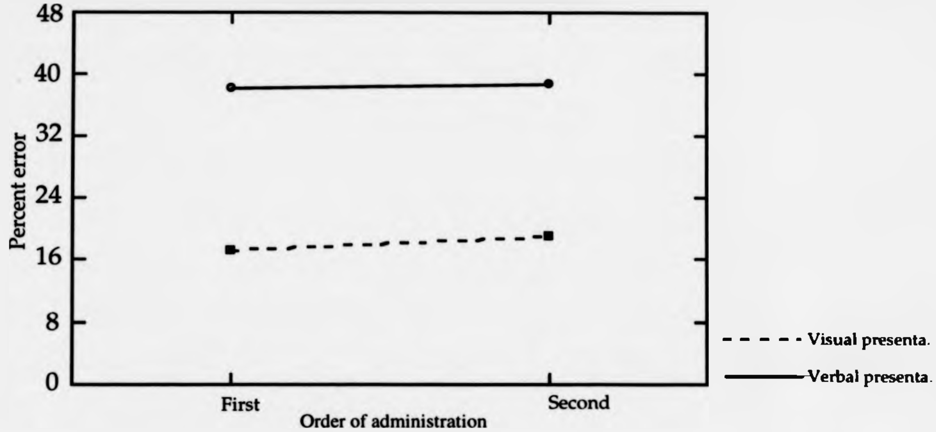


Figure 4.7. Mean percentage of error made when either form of the task was administered first or second.

It is clear from the above figure that no practice effects occurred. Taking either form of presentation second did not lead to better performance in comparison to taking it first. There was also no interaction between order of administration and presentation modality. Verbal presentation was not significantly harder when it was given first. Hence, in contrast to Experiment 2-a, visually encoding the Brooks task first did not provide more effective training and familiarisation with the task than did verbally encoding it first. The presence of the matrix at encoding did not provide more effective learning and practice as occurred in Experiment 2-a. Some factors may have contributed to this result. First, in this experiment there were only 2, rather than 4, interference conditions. These two conditions were rated by subjects as the hardest conditions since they involved spatial and rhythmic tapping. There were no control and simple tapping conditions which appear to provide more training and familiarisation with the Brooks task since in the control condition subjects perform the Brooks task alone and in the simple tapping condition they perform the Brooks whilst concurrently carrying out the simple tapping task which is considered to be much easier than the other tapping tasks. Another factor is that in this experiment subjects complied more with the tapping instructions, as will be discussed later, and hence performed and treated the two concurrent tasks equally. Thus, there was much less opportunity for familiarisation with the *tests* of the Brooks task. The spatial and rhythmic tapping conditions appear to require a division of effort and attention between the memory task and the tapping task and, hence, more errors occurred and perhaps less learning and familiarisation with the Brooks task material.

An analysis of the SP effect was carried out on the data of both verbal and visual presentation in order to find out the nature of the SP curves and whether more errors were made at the beginning or at the end of each set of 8 sentences (positions). Errors made at each of the 8 serial positions under each form of presentation were counted. 8 subjects were tested and each was given 6 testing trials under each presentation modality, thus each position had 48 chances of being error. Figure 4.8 shows the mean percentage of error at each SP under both presentation modalities.

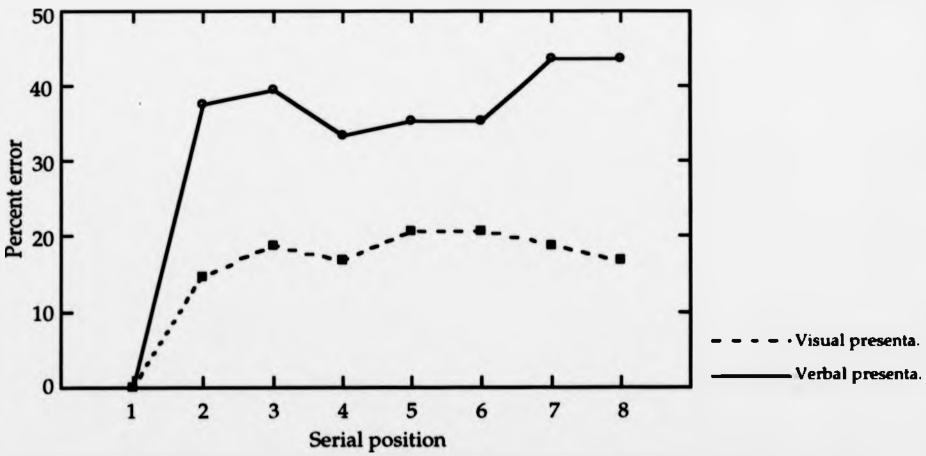


Figure 4.8. The SP curves for verbal and visual presentation of the Brooks matrix task.

The two curves shown in figure 4.8 appear to be parallel with relatively similar numbers of errors being made at positions 2-8. As usual, no errors are made at position 1 since it involved no spatial adjective and was always the same sentence, *'In the starting square put a 1'*. Therefore, position 1 was excluded from the SP statistical analysis. A 2(presentation modality) x 7(serial positions) within subjects repeated measures ANOVA was performed on this SP data with presentation modality as the independent factor and positions 2-8 as the repeated measures variable. This analysis showed a significant main effect presentation modality [$F(1,7)=13.76$, $p=0.01$]. More errors were made under aural presentation. There was no significant main effect of SP [$F(6,42)=0.41$, $P=0.87$]. Similar numbers of errors were made at positions 2-8. The interaction between presentation modality and SP was not significant [$F(6,42)=0.63$, $p=0.70$]. The two curves are parallel.

In regard to the VMIQ, subjects' ratings on the VMIQ were correlated to the numbers of errors they made on the Brooks task. A Spearman correlation test showed no significant correlation between ratings on the VMIQ and performance on the Brooks Matrix when it was presented aurally (rho=0.14, $p>.05$) and when it was presented visually (rho=0.29, $p>.05$). This result replicates the result obtained in Experiment 2-a. The correlation between subjects' performance on the 'verbal' Brooks and the 'visual' Brooks task was not significant (rho=0.17, $p>.05$).

4.3.4. Discussion

This experiment explored the issue of noncompliance with the tapping instructions in general and the rhythmic tapping instructions in particular. In Experiment 2-a, this noncompliance was proposed to be a factor behind the absence of an interaction between interference condition and presentation modality of the Brooks task. Rhythmic tapping was predicted to selectively interfere with performance of the Brooks task when it was presented aurally but not visually. This predicted interaction did not occur in Experiment 2-a. In this experiment, it was hypothesised that if subjects performed the secondary tasks to the criterion by complying with the tapping instructions, such predicted interaction would occur.

Results showed that, although there was a much higher level of compliance, this interaction did not occur. Evidence for this compliance will be presented in a subsequent section. Thus, the results replicated and confirmed the results of Experiment 2-a which showed that rhythmic tapping had no selective interference effect but rather interfered with performance of the Brooks Matrix regardless of presentation modality. The theoretical implications of this result to the structure and theory of WM will be discussed in the general discussion section. But first the results of this follow-up experiment will be thoroughly discussed.

The results (see figure 4.6) showed no interaction between presentation modality and movement interference condition. There was also no difference between spatial and rhythmic tapping conditions under each form of presentation of the Brooks Matrix task. As can be seen in table 4.a, subjects made similar numbers of errors at both the spatial and rhythmic tapping conditions. This pattern occurred equally under both presentation modalities. As in Experiment 2-a, performance under visual encoding was superior to performance under 'aural' encoding. The overall mean percentage of error under visual presentation was only 18.14 whereas it was 38.43 under verbal presentation. All subjects reported that the task was much easier when it was encoded visually. When asked about the reasons for this, typical replies were as follows: *"with visual presentation you don't need to translate (convert) what you hear into images or a vision of the grid; with verbal presentation there were two things to listen to, the sentences and the signal; with verbal encoding it is easy to lose the image (shape, snake, etc.) that I was building up; with visual presentation I see the matrix directly and try to imprint it in my head"* and so on.

Moreover, subjects were asked about the strategy they relied on when processing the Brooks task. All subjects indicated relying on their visual imagery to perform the task regardless of its presentation form. With verbal presentation, some subjects indicated that they attempted to create a *picture* of digits within the 'grid' and break it up into smaller blocks or shapes with the first 4 digits sometime in one block and the last 4 digits in another block. The shape was then used to recall the digits. During this aural encoding, some subjects indicated that if the location of a digit is lost, then the sequence or shape is lost to visual memory. With visual presentation, very similar comments were obtained but subjects often reported forming a shape or a 'snake' with no clear boundaries of the 'grid' (matrix). The overall strategy for both input modalities seems to be visualising the digits as a shape or a pattern and then attempting to read it off at the verbal retrieval.

Each subject was also asked to rate the difficulty of each interference condition relative to the other condition. For visual presentation, 5 out of the 8 subjects indicated that rhythmic tapping was the hardest whereas 2 subjects indicated that spatial tapping was the hardest and 1 subject indicated that there was hardly any difference between the two conditions. Subjects who found rhythmic tapping to be harder indicated that this was because *"it required attention, it is not regular and thus it is more conscious, it required concentration and thinking about both tasks"*, and so on. For aural presentation, 6 out of the 8 subjects indicated that rhythmic tapping was the hardest whereas 1 subject found spatial tapping to be harder and the last subject found both conditions to be equally very hard. Subjects again indicated that rhythmic tapping was harder because: *"it requires more attention and judgement; it is irregular and thus puts me off sometimes; it requires concentration and thus makes me lose the image; both visualising and tapping a rhythm require equal concentration"* and so on. Subjects who reported finding spatial tapping to be harder indicated that this was because there was a pressure in finding and hitting the tapping targets accurately and that it was very distracting if a target were missed.

<u>The SP analysis:</u>

The SP curves for both presentation modalities were parallel. No primacy or recency effects occurred and similar numbers of errors were made at positions 2-8. Unlike free-recall experiments in which primacy and recency effects occur, in this experiment recall was constrained. Subjects recalled the locations of the digits in the same order in which they were presented and in 'spatial' relation to one another within the matrix. In addition, subjects carried out concurrent tapping tasks during the encoding of the material. In order to compare these curves to the curves obtained in Experiment 2-a, which had 4 interference conditions, SP curves were constructed for Experiment 2-a involving only the spatial and rhythmic tapping conditions (see figure 4.9).

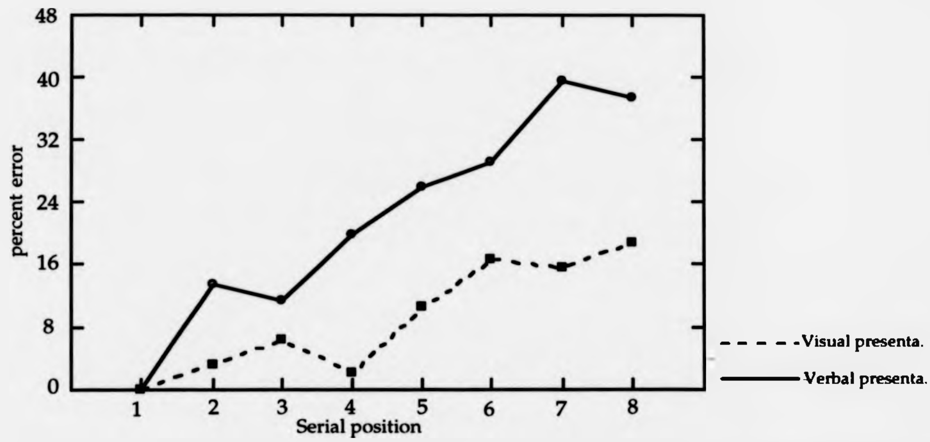


Figure 4.9. The SP curves for verbal and visual presentation of the Brooks task in Experiment 2-a involving only the spatial & rhythmic tapping conditions.

From figures 4.8 and 4.9, it is clear that there is a difference between the SP curves obtained in the two experiments. In Experiment 2-a, there was a primacy effect and a 'negative' recency effect. Error rate increased approximately linearly with SP. This result in Experiment 2-a was interpreted as follows: subjects usually report that during encoding they use their visual imagery to build up a *shape* (a pattern) representing the digits relative to one another within the matrix. This shape, sometimes referred to as a 'snake', is then used as a cue at retrieval to recall the locations of the digits by reading them off that shape. Subjects usually report a difficulty in recalling the last few items due to a tendency to lose the end of the shape or as some subjects put it *"the end of the shape just fades away"*. This could explain the low error rate at the primary items and the large increase in error rate towards the last few positions.

However, in this experiment a different pattern occurred. There was no primacy effect and error rate was relatively similar at positions 2-8. This pattern could be due to the fact that, unlike in Experiment 2-a, there was more compliance with the tapping instructions and thus more interference. Performing the secondary tapping tasks to the criterion during encoding probably influenced the processing and recall strategy of the Brooks task by interfering with the forming of a mental image (shape) representing the digits within the matrix. In the previous experiments, subjects often reported relying on forming an image (a shape or a 'snake') representing the items relative to one another and using that shape as a cue at retrieval to read off the items. Subjects reported a difficulty in recalling the most recent items because the end of the shape tended to fade away and thus these items were lost to visual memory. In this experiment, there was more compliance with the tapping instructions which resulted in more interference and thus more errors. Such compliance may have led to more interference with the forming of the image during encoding. Thus, with no clear image to read off, errors were made relatively equally at all serial positions. With no such clear shape the primary items probably did not have the advantage of being recalled before the shape begins to fade away as occurred in the previous experiments.

Tapping performance:

This experiment examined the issue of non-compliance with the tapping instructions in Experiment 2-a which was proposed as a possible factor behind the absence of the predicted interaction between presentation modality and interference condition. To bring about more compliance, stringent introduction and tapping instructions were used which emphasised the dual-task nature of the experiment and the crucial importance of performing the two tasks concurrently and treating them equally. Throughout testing, subjects were also periodically reminded of the instructions. During testing, the experimenter observed that subjects mostly complied with the instructions. In contrast to Experiment 2-a, subjects took the tapping tasks more seriously and attempted to treat the two concurrent tasks equally by not concentrating on one more than the other. Subjects in the rhythmic tapping condition were made more aware of the importance of trying not to miss any of the variable signals and attempted to comply with this instruction. In general, subjects' tapping appears to be in time to the auditory signals. Such compliance is reflected in the higher error rate on the primary task in comparison to Experiment 2-a. Under verbal presentation, the mean percentage of error in the spatial tapping condition in Experiment 2-a was 25.29 whilst it increased in this experiment to 38.69 (an increase of 53%). Similarly, the mean percentage of error in the rhythmic tapping condition in Experiment 2-a was 25.29 whereas it increased here to 38.10 (51% increase). Under visual presentation, the mean percentage of error in the spatial tapping condition in Experiment 2-a was 10.43 whereas it increased here to 16.67 (60% increase). Similarly, the mean percentage of error in the rhythmic tapping condition in Experiment 2-a was 10.43 whilst it increased here to 19.64 (88% increase). To provide further evidence for these observations, the tapping records were scored and analysed as follows:

Tapping data

Tapping performance was recorded by the Event Recorder. The tapping records for each condition were examined to find out whether subjects performed to the tapping criterion. The procedure and results for each condition were as follows:

a) Spatial tapping:

In order to find out how regularly and accurately subjects tapped round the 4 plates under both presentation modalities, spatial taps made by each subject on the thermal paper were examined and counted for every trial. Subjects tapped round the 4 targets in turn in a clockwise direction at the rate of 1 tap per second. The taps on each plate were recorded by the corresponding channel, in the Event Recorder, in their designated space on the thermal paper. When this Recorder is operated, the thermal paper moves at the speed of about 7.5mm per second.

Therefore, it is possible to examine compliance with the tapping instructions by checking the tapping records to see if subjects missed any of the 4 targets in every tapping sequence (a sequence of 4 taps round the 4 plates). The results were as follows:

For visual presentation: In each interference condition, each of the 8 subjects was given 3 trials. Thus, a total of 24 trials were performed in each condition. The tapping records showed that in 20, out of 24, trials, subjects did not miss any of the 4 targets whereas they missed some targets in the remaining 4 trials.

For verbal presentation: In 18, out of 24, trials, subjects did not miss any target during tapping whereas they missed some targets in the remaining 6 trials.

To examine the significance of these missed targets (errors), performance in each of these trials was compared to the *expected* sequence which was 1 tap in its designated space on the thermal paper every 1 second. Paired samples t-tests showed that under visual presentation only 1 of the 4 trials significantly differed from the expected sequence ($t=2.18$, $df=19$, $p=0.04$). Under verbal presentation, similar t-tests showed that none of the 6 trials significantly differed from the expected sequence ($p>0.05$). Thus, subjects' overall spatial tapping in this experiment was regular and mostly conformed to the criterion of tapping round the 4 targets in turn in a clock-wise direction and in time to the signal.

b) Rhythmic tapping:

The rhythmic tapping records were examined and, in comparison to Experiment 2-a, showed greater compliance with the tapping instructions. From visual inspection, the records for most of the trials showed that subjects were attempting not to miss the signals as they were instructed. However, in some trials particularly under verbal presentation, it was clear that a few signals were not responded to or the reaction time for another few signals was longer than expected. In dual-task paradigms such a finding is expected. When two *'similar'* tasks are performed concurrently some mutual interference is anticipated. Rhythmic tapping and verbally encoding the Brooks Matrix are similar in that they are hypothesised to involve a common WM resource, the CE.

As in Experiment 2-a, tapping in each trial was measured in mm on the thermal paper. To find out to what extent subjects' tapping correlated to the standard tapping rhythm, the *obtained* tapping intervals in each trial were correlated to the *expected* rhythmic tapping intervals. The expected temporal rhythmic intervals of 0.41, 1.0, 1.67, 0.92 seconds were found in Experiment 2-a to correspond to a sequence of 4-8-11-7mm intervals on the thermal paper. In each trial, this sequence is repeated for the duration of the trial resulting in an expected sequence of: 4-8-11-7-4-8-11-7-etc. The analysis was as follows:

<u>For verbal presentation:</u>

8 subjects were tested and each was given 3 trials in each interference condition. Thus, in this condition there were 24 trials. Tapping performance in each trial was measured as intervals in mm. The *obtained* tapping intervals for each trial were then correlated to the *expected* sequence of rhythmic intervals. Pearson correlation tests showed that tapping in 18, out of 24, trials significantly and positively correlated with the expected intervals ($p<0.05$) whereas the remaining 6 trials did not correlate with the expected intervals ($p>0.05$). The correlation coefficients for all of the 24 trials were averaged. The resulting average correlation coefficient was $r=0.64$. This coefficient is much higher than its counterpart in Experiment 2-a which was only $r=0.43$.

<u>For visual presentation:</u>

The same procedure described above was followed. The Pearson correlation tests showed that tapping in 19, out of 24, trials correlated positively and significantly with the expected rhythmic intervals ($p<0.05$) whereas the remaining 5 trials did not correlate with the expected intervals ($p>0.05$). The correlation coefficients for all of the 24 trials were averaged. The resulting average correlation coefficient was r=0.72. This coefficient is much higher than its counterpart in Experiment 2-a which was only r=0.55.

Thus, it appears that, unlike Experiment 2-a, subjects' rhythmic tapping in this experiment showed more compliance with the tapping instructions. With visual presentation, subjects tapped better than they did with aural presentation. To find out how significant this difference was, the correlation coefficients for the 24 trials under aural presentation were compared to their counterparts under visual presentation. A paired samples t-test showed no significant difference (t=1.06, df=23, p=0.30).

From the above observations and results, subjects appear to have complied with the tapping instructions and reasonably tapped to the criterion. However, as discussed in Experiment 2-a, in a dual-task paradigm optimum performance on the secondary tasks is not expected particularly if both the secondary and primary tasks are similar in terms of their processing demands. Rather, a degree of mutual interference is usually anticipated (refer to the discussion of Experiment 2-a for a discussion of multiple resource theory and the concept of cost of concurrence). Therefore, it was expected that when rhythmic tapping was concurrently performed with the 'aural' Brooks Matrix, some inefficient performance on both tasks might occur since both are considered by the proposed process model to be similar in terms of competing for a common WM resource, the CE. Similarly, it was expected that when spatial tapping is concurrently performed with the Brooks Matrix (regardless of presentation modality), some inefficient performance on both tasks may occur since both tasks are considered to be similar in terms of involving a common WM resource, the VSSP.

4.4. General discussion

Results of this follow-up experiment has replicated the findings of Experiment 2-a. Spatial tapping, which is presumably a spatial suppression task, disrupted performance on the Brooks Matrix regardless of presentation modality. Therefore, encoding the Brooks Matrix task appears to involve a visuo-spatial resource within WM. Such a result has been widely reported in the literature (e.g. Baddeley & Lieberman, 1980; Quinn, 1991). Concurrent spatial tapping still disrupts processing of the Brooks task when it is visually encoded. Visual presentation of the Brooks task was supposed to remove the image generation element of the task and makes it heavily reliant on the VSSP for its processing.

Similarly, rhythmic tapping which is presumably a CE task, disrupted performance on the Brooks Matrix regardless of presentation modality. Visually encoding the Brooks Matrix was assumed, by the process model, to require no image generation from LTM and thus to minimise the CE involvement since there is no longer any need for switching attention to search for information from which to generate images. Rhythmic tapping was thus predicted not to interfere with such encoding. However, rhythmic tapping which requires concentration and attention, was predicted to interfere with aurally encoding the Brooks Matrix since this encoding requires the involvement of the CE to switch between the current aural input (Brooks sentences) and the generation of visual images of the matrix from LTM. This predicted interaction was not supported by the results of both this experiment and Experiment 2-a. This result has some implications for the structure of WM and the role of the CE in WM as will be discussed in the next section.

A general aim of the previous experiments was to investigate the relationship between the VSSP and the CE and whether a dissociation between them could be established. After an early debate about the status of the VSSP and whether there is any need for a specialised visuo-spatial WM system separate from a CE (e.g. Phillips & Christie, 1977a; Phillips, 1983), some researchers indicate that there is now little doubt that such a system exists as a functionally separable system within WM (Quinn, 1991; Farmer et al, 1986; Baddeley, 1988; Logie et al, 1990). However, there seems to be no conclusive evidence regarding the relationship between the VSSP and the CE and whether a clear dissociation could be established between them. In the WM literature, there is strong support for the view that visuo-spatial and verbal STM functions are conceptually dissociable (e.g. Baddeley & Lieberman, 1980; Baddeley et al, 1975b; Farmer et al, 1986). Logie et al (1990) after reviewing various sources of evidence concluded that there is support for a visual STM that is independent of verbal temporary storage and is involved both in the generation of visual images and in visual perception. But, there is no conclusive evidence that a clear dissociation exists between the slave systems and the CE. Logie (1991) indicates that it is not clear to what extent the VSSP is a specialised visuo-spatial memory and a visual processing system as opposed to a system that relies heavily on general attentional resources (e.g. Avons & Phillips, 1987; Phillips, 1983) such as the CE component of WM. For instance Morris (1987) reported that visuo-spatial processing was vulnerable to a secondary task during encoding and at retrieval, but was relatively insensitive to disruption during a maintenance interval. Logie points out that such results might suggest that the data from dual-task type experiments are tapping a CE type of resource which is involved in encoding and in retrieval of information, but is not involved in maintenance of such information. Thus, there is a clear difficulty in demonstrating the existence of a VSSP that is separate and dissociable from the CE. Logie et al (1990) argued for the existence of a separate, specialised visual STM system, but a system that also require certain amount of monitoring by a general purpose resource.

Logie et al and also Logie & Baddeley (1990) indicated that such a conclusion that a separate VSSP exists has a difficulty since in the WM model there are at least three mechanisms involved: an AL, a VSSP, and a CE. To demonstrate the existence of three systems, the dissociation technique would have to be more sophisticated than a double dissociation technique. One approach, they suggested, would be to attempt a triple dissociation, in an experiment with 9 contrasting conditions. However, the CE is very different in complexity and in nature to the two 'slave' systems. Therefore, a triple dissociation would be extremely difficult if not impossible to achieve. It is suggested that a more viable research strategy is to use the procedure of converging operations, that is to provide evidence from a variety of sources and experimental manipulations and paradigms which will converge on a comprehensive and coherent account. This approach has been very successful in the development and understanding of the AL with the effects of word length, phonological similarity, articulatory suppression, and unattended speech all converging on the current view of the operation of the AL (see chapter 1 & Baddeley, 1986). Logie & Baddeley indicated that such a converging evidence is beginning to accumulate for the VSSP. However, they pointed out that the VSSP area is ripe for further exploration and that the VSSP is still the poor sibling of the AL in terms of research effort. Many issues still need further clarification such as, they suggest, the relationship between the CE and the VSSP and the possible separation of function between the spatial and visual processing of material.

The previous experiments attempted, in line with the above suggestion, to investigate the relationship between the VSSP and the CE by manipulating the method of presentation of the Brooks Matrix task in a way that presumably minimised the CE involvement in its encoding. This modification presumably made the task easier and thus less prone to being dependent on CE resources but rather on a specialised visuo-spatial WM mechanism. An aim of this modification of the Brooks task was to enable further elucidation of the VSSP vs the CE issue. In the literature, studies that attempted to investigate the role of movement in WM often attempted to manipulate the secondary, rather than the primary, visuo-spatial tasks in order to minimise attention in their performance while using visuo-spatial primary tasks, such as the SB task, that are presumably difficult and involve the CE. For instance, Quinn (1988a, 1991; Quinn & Ralston, 1986) used the technique of passive movement as a secondary task and examined its effect on performance of the Brooks Matrix. It was found that passive incompatible movement disrupted performance on the Brooks Matrix but that the interference was limited to the active encoding stage as opposed to image maintenance. It was concluded that movement itself, rather than attention to the movement, is involved in spatial processing. However, Logie & Baddeley (1990) pointed out that even with the passive movement technique, subjects may covertly monitor and try to process in some way the movement of their hands.

The Brooks Matrix has been indicated in the literature to require heavy CE involvement for its active processing (see chapter 2). For instance, Logie & Marchetti (1991) argued that the CE is involved in encoding the Brooks Matrix material in some form of mental image but is less important for maintenance of the information. Salway (1990, 1991) indicated that the matrix task requires a greater input from the CE component and may therefore involve more general purpose load and thus be more difficult than its verbal equivalent. Quinn (1990, 1991) pointed out that many experiments showing interference effects in the VSSP have arguably confounded their interpretation by failing to control CE effects. Any experiment which has as its goal a more precise delineation of interference effects in the VSSP must attempt to minimise the contribution of attention.

Hence, Experiment II attempted to minimise the involvement of the CE in the encoding of the Brooks Matrix task by presenting it visually. The cognitive processes involved in performance of this task were examined by Experiment (I) in which the methods of presentation and recall were varied between verbal and visual modalities. The important result of that experiment was that visual, as opposed to aural, encoding of the Brooks task led to superior recall. A process model was proposed to account for this result. Briefly, it was assumed that with visual input, no heavy image generation from LTM is required and no switching of attention is required to search for information from which to generate images and this could account for the superior recall. In other words, it was proposed that with visual presentation the involvement of the hypothetical CE in encoding the matrix material has been minimised. Hence, Experiment 2 was conducted with the overall aim of attempting to tease apart the VSSP and the CE components of WM. It was hypothesised that a CE task (rhythmic tapping) that has no spatial component should only interfere with aural, but not visual, encoding of the Brooks Matrix. It was also hypothesised that a spatial 'suppression' task should interfere with performance of the Brooks regardless of presentation modality.

As the results of experiments 2-a&b showed, spatial tapping disrupted performance of the Brooks Matrix task under both forms of presentation but the predicted interaction did not occur. Rhythmic tapping also disrupted performance even when the task was visually encoded. The proposed process model has not been fully supported. The results of these experiments do not support the view that the VSSP is independent and separable from the CE. The VSSP can not be described as a passive 'screen' on which visuo-spatial information is 'painted'. It appears to involve more than just a simple buffer on which visuo-spatial information is imprinted, but rather it seems to involve active processing and general attentional resources.

The above results lend support to many results and conclusions already reported in the literature. For instance, Logie et al (1990) argued for a separate VSSP that also requires a certain amount of monitoring by the CE. Logie & Marchetti (1991) pointed out that their data along with recent evidence might suggest a high involvement of the CE in encoding and processing spatial information or generating visual images. Morris (1986b, 1987) examined the role of the CE in controlling the encoding operations of the VSSP and proposed that the CE is 'coupled' to the VSSP during active encoding of spatial material and that this coupling is broken during maintenance rehearsal to liberate executive resources for other tasks after such encoding. Morris argued that the CE is probably required to operate the VSSP in most circumstances except during maintenance rehearsal. It is indicated that the VSSP can operate independently of the AL but that the CE resources seem to be required during encoding and retrieval operations. Morris & Jones (1990) pointed out that this conclusion by Morris implies that the WM system acts as an integrated system during active processing and that the system will 'resist' fractionation during these phases because the demand characteristics of the task require this 'cohesion'.

Morris & Jones indicated that there was a difficulty in fractionating the CE/slave system complex because it is difficult to isolate the executive due to its 'time-sharing' capabilities. The CE probably has the ability to redeploy its resources very rapidly to coordinate complex cognitive processing. Hence, slave systems can be dissociated from each other by employing interference activities that are specifically aimed at a given system. However, the CE may only be isolated by either presenting a demanding dynamic memory task, interfering with the locus of control, or by finding appropriate neurological deficits.

In addition, Morris (1989) proposed that spatial WM would probably consist of a scratch pad of limited capacity plus an attentional monitoring mechanism within the CE complex. This complex could engage in active processing and thus spatial WM can be seen as a distinct domain of processing (Baddeley, 1982). The CE (Baddeley, 1986) is a modality-free controlling and supervisory mechanism of limited capacity. It is (Van der Linden et al, 1992) the core of the WM model which is assumed to play a role in the selection, planning, and control of the various processes used in short-term storage and more general processing tasks. Van der Linden et al indicated that, following Morris & Jones (1990), the CE is especially involved in the co-ordination of WM updating in real time. This central processor also contributes to the regulation of the slave systems and to the integration of information from these and from LTM.

Finally, the results of this experiment appear to be in line with some recently reported results and conclusions. For instance, Logie (1993b) argued that his data, together with other closely related findings in the literature, suggest that many imagery processing tasks rely heavily on general purpose cognitive resources and that the slave-systems in WM are involved only when required to provide temporary storage through the buffering of sensory input, of speech motor output, and of targeted movement. A relevant finding to this suggestion was reported by Farah (1989) who suggested that imagery may well represent an attentional state.

In conclusion, this experiment attempted to establish a dissociation between the VSSP and the CE by using a primary visuo-spatial task that has been modified to minimise the CE involvement in its encoding. The results do not support such a dissociation during the encoding stage. The CE appears to be required for active spatial and motoric processing. The CE may have a possible role in the activation of motoric and spatial elements and representations in STM.

VMIQ:

The results of Experiments 2-a&b showed that subjects' performance on the Brooks task did not significantly correlate with their subjective ratings on the VMIQ. The interpretation of this result is not straightforward. Subjective imagery measures are usually open to question, and also it is not clear whether or not the Brooks Matrix and the VMIQ rely on and measure the same ability. The VMIQ consists of items that relate to visual imagery of movement and imagery of kinesthetic sensations associated with movement and has been suggested (Isaac et al, 1986) to be a valid measure of an individual's ability to produce images of movements. The Brooks task is supposed to be a visuo-spatial STM task that depends on a visuo-spatial WM resource for its processing. While the Brooks task is an imagery task, it does involve memory and this memory for an imagined set of locations of digits involves the creation of an array that once created (Logie & Marchetti, 1991; Quinn, 1991) then subjects may need only to retain a static visual pattern of digits in an imagined matrix. A passive visual store within visuo-spatial WM (Logie, 1989) could be involved in retention of such static visual pattern while an active visual rehearsal process, which is related to the control of movement in visual STM, could be involved in encoding the Brooks task. If the Brooks task relies on pure visual imagery for its retention, then a more specific measure of visual imagery may be more appropriate to predict performance on the Brooks task than the VMIQ which is specifically concerned with visual imagery of movement and the imagery of kinesthetic sensations associated with movement.

One such measure of visual imagery is the VVIQ developed by Marks (1973a). The VVIQ (see chapter 2 & Appendix 1.2) consists of only visual items that refer to common situations and scenes and the task is to rate the vividness of the visual imagery the items evoke. Marks (1972) argues that the VVIQ is a valid discriminator of subjects with good and poor visualising ability. It would be interesting to see, in future experiments, if subjects' performance on the Brooks task would significantly correlate with their visual imagery vividness as measured by the VVIQ. If vividness ratings of visual images and recall of the locations of digits within a matrix are both mediated by the same covert event - a visual image - then some correlation should be expected. Marks (1973a&b) found that ratings on the VVIQ were reliable predictors of accuracy of recall of information and details contained in pictures. Marks interpreted such result as providing further evidence that images have an important function in memory such as the finding that image vividness facilitates accurate recall. It, however, should be pointed out that according to Isaac et al (1986) there is a significant correlation (r=0.81) between ratings on the VVIQ and the VMIQ which has been interpreted as suggesting that the VMIQ is a valid instrument concerning the visual imagery of movement. If this is the case, then ratings on the VMIQ are supposed to correlate with performance on the Brooks Matrix which, in turn, is assumed to rely on visuo-spatial imagery.

Chapter 5

Simplifying the Brooks Matrix task into a 'pure' visuo-spatial task

5.1. Introduction:

Experiment 2-a examined the proposed process model of the Brooks Matrix task using an interference paradigm. The question asked was whether movement would interfere equally with performance under verbal and visual presentation. Visual presentation made the Brooks task very much easier and it is thus possible that the effect of concurrent movement is to interfere with the image generation component of the task. It was hypothesised that a presumably spatial suppression task would interfere with performance under both forms of presentation. A simple tapping movement that does not involve a spatial array was predicted not to interfere with performance under any form of presentation. The differential disruption was predicted to come from a CE (rhythmic tapping) task that requires attention and concentration but requires no reference to a spatial context. This task was predicted to interfere only with performance under verbal presentation. Results showed that whilst spatial tapping disrupted performance under both presentation modalities, the predicted interaction did not occur. Rhythmic tapping also disrupted performance under both forms of presentation. Due to the experimenter's observation and to the analysis of the tapping data which showed that subjects did not, to some extent, comply with the rhythmic tapping instructions, a follow-up experiment was conducted. This experiment included only the spatial and rhythmic tapping conditions and subjects were explicitly instructed to treat the two concurrent tasks equally by not concentrating on one task more than the other. Although there was greater compliance, the results simply replicated the results of Experiment 2-a. Spatial and rhythmic tapping equally disrupted performance under verbal and visual presentation.

Hence, these results have shown that although the CE involvement in encoding the Brooks task had been presumably minimised by presenting the task visually, a CE task still disrupted performance as much as did a spatial movement task. This result has been interpreted as suggesting that CE resources are required during the active encoding of visuo-spatial information and that the VSSP cannot be described as a passive 'screen' on which visuo-spatial information is 'painted'. In other words, the VSSP appears, so far, to be more than just a simple buffer on which visuo-spatial material is imprinted, rather the CE appears to be required to operate such a system. It is thus not clear whether concurrent movement interferes with the visuo-spatial representation as such or with this CE involvement.

However, such an interpretation may be premature since the Brooks task is still not a purely visuo-spatial task. The method of recall used in Experiments 2-a&b was verbal. Subjects remembered the locations of the digits by attempting to form a mental image representing the digits relative to one another within the matrix and then using that image at recall to help in repeating the 8 sentences when presentation was verbal, or in constructing identical sentences when presentation was visual. This decoding process may require some CE involvement since image generation is still required to read off the visual image at recall. Switching between visuo-spatial and verbal modalities may involve operations of the CE (Holding, 1994). The visual image is often described by subjects as a 'shape', a 'pattern', or a 'snake' which represents a path around the squares of the matrix as described by the sentences or shown by the slides. Subjects typically report using this "snake-like" visual image to generate the sentences during recall. Recall difficulties are usually attributed to losing the *shape* to visual memory. In particular, subjects report that during the generation of the sentences from the retained image, the end of this *shape* fades away which might explain the higher error rate associated with recalling the locations of the last few digits.

Thus, it appears that the Brooks Matrix task has not yet been stripped of all of its redundant CE and verbal codes and processes. This task, in its original form, has turned out to involve not only the retention of visuo-spatial information but the

generation of visual images from verbal instructions during the 'acquisition' phase and the ***generation*** of sentences from a visual image during the recall phase. These two additional encoding and decoding processes probably obscure our understanding of the VSSP and the role of movement in it. It is assumed that these additional processes involve an *attentional resource* and that whenever interference is shown to be not modality specific, the CE is presumed to be involved.

In terms of the Annett's (1982, see chapter 1) ALI model, these two additional processes are equivalent to crossing and re-crossing the A-L bridge. The CE is presumably involved in the crossing of the A-L bridge. Whenever there is a translation from the 'language system' to the 'action system' or vice versa, the CE resources are assumed to be involved in such translations. Annett (1982, 1994b) suggested that an approach to determining the properties of the A-L bridge is to carry out a programme of convergent experiments using the different paradigms illustrated in figure 1.6 which require translations in one direction or the other across the bridge. Such experiments would require subjects to follow or to generate verbal instructions since both activities require translation of one form of encoding to the other. Figure 1.6 also shows a minimal set of basic concepts and the relationships between them as routes on a map, each route representing an experimental procedure. Annett identified 8 types of experiments which are thought of as routes through his proposed model. Six of these (routes 2, 3, 5, 6, 7, & 8) were indicated as 6 basic experiments that represent routes from the external world of objects and events, 3 of which, shown on the left side of the diagram, produce nonverbal actions and the other 3, shown on the right of the diagram, produce verbal or written responses. Routes 3, 6, 7, & 8 all imply a translation between verbal and nonverbal coding (a link between the action and language systems) and this is the hypothetical A-L bridge.

These four routes which represent the A-L bridge all involve crossing the bridge and translation between verbal and nonverbal coding. Within this context, it could be thought of some of the manipulations in the encoding and decoding modalities of the Brooks Matrix in terms of some of these proposed routes. These manipulations were examined by Experiment (I). The first encoding-decoding combination (verbal-verbal), the second (verbal-visual), and the third (visual-verbal) could all be considered as involving crossing or recrossing the A-L bridge. Thus, these three manipulations could be linked to some of the A-L bridge routes. For instance, the second manipulation (verbal-visual) would fit into route 3 whilst the third (visual-verbal) would fit into route 6 (see figure 1.6). The fourth manipulation (visual-visual) involves no crossing of the A-L bridge and could be considered as an experiment representing route 2 as will be discussed shortly.

In Experiment II which used a movement interference paradigm, the Brooks Matrix task was presented aurally or visually and was recalled verbally. With verbal presentation, subjects were supposed to listen to the sentences and retain the material as a mental image in the VSSP (the action representation system) through the generation of images from the sentences. At recall, they were supposed to reconstruct the sentences by generating them from that mental image. These processes involve crossing and recrossing the A-L bridge. They also involve CE resources since the CE is presumably required during these generation and switching processes. With visual presentation, the material were encoded directly from the visual display (through the action system within Annett's model) which does not require image generation. But during the verbal recall, subjects were required to construct and generate sentences from the retained mental image. Thus, there is crossing of the A-L bridge during this verbal decoding and presumably CE involvement to generate sentences from the stored visuo-spatial representation. In general, it is not clear whether concurrent movement interferes with the VSSP as such or with these extra cognitive processes such as crossing the A-L bridge and CE involvement.

It was thus suggested that a more accurate understanding of the nature of the VSSP and the role of movement in this proposed WM component would result if the Brooks task was purified and stripped of all of these redundant codes and processes. Such a variant of this task should involve no crossing of the A-L bridge and no heavy CE involvement. Within the Annett's model (see figure 1.6), this variant should involve only the '*human action system*' and hence should not require any translation between the action and language systems. In terms of Annett's description of six possible basic experiments as routes through his proposed model, this simplified variant would represent route 2 in which both input and output are non-verbal 'actions'. According to Annett (1982) this route has received rather less attention and, apart from some studies on imitation, there do not appear to be any studies of motor memory which are strictly analogous to the classical verbal memory paradigm. Annett pointed out that his proposed crude framework has therefore revealed a gap in the literature which ought to be filled with potentially interesting experiments since motor memory is usually investigated by a quite different paradigm. As can be seen in figure 1.6, route 2 is analogous to route 5 and both represent imitative or echoic responses. Route 5 involves both a language input and language output. Therefore, route 2 could be conceptualised as purely involving the VSSP subsystem of WM whereas route 5 could be conceptualised as involving the AL. In short, the results have so far shown that the Brooks Matrix is a complicated task. In line with the suggestion by Annett regarding the need for experiments representing route 2 in his model, it appears that this task needs to be purified from some redundant processes in order to make it appropriate for exploring motoric or visuo-spatial STM.

One very clear result of the previous experiments is that visual, as opposed to verbal, presentation of the Brooks Matrix makes this task much easier presumably because no image generation, and thus no CE involvement, is required. It is also apparent that there are extra verbal and CE processes involved in encoding and decoding this task which may obscure our understanding of why and what sort of movement interferes with this task. It is thus plausible to continue modifying this task until a simplified visuo-spatial variant is reached. Such a variant should then enable examining whether movement interferes with the VSSP as such, not just by adding to the load on the CE. The CE is assumed to be heavily involved during aural encoding (generating images from sentences) and verbal decoding (generating sentences from a visual image). Hence, a simplified variant which is stripped of all unnecessary processing is needed. This variant should involve visually presenting the task material in order to remove image generation and it should involve 'visual' recall in order to remove the need for generating sentences from a mental image. These two changes will in effect eliminate any need for crossing or recrossing the A-L bridge. Such a variant was examined by Experiment 1-d as the fourth variation in the modalities of presentation and recall of the Brooks Matrix. In that experiment, subjects responded by arranging cards containing the digits (or objects) on a real matrix. However, recall under that variation was less efficient than recall under the third variation (visual-verbal) despite the apparently direct coding and decoding as there was no crossing of the A-L bridge and it was a 'route 2 experiment'. Arranging and sorting the cards was thought to have interfered with the retained visual image and led to the relatively less efficient recall. A more direct method of visual recall is apparently needed.

Since the VSSP is essentially a conscious process then subjective reports can provide a guide. Many subjects report that they rely heavily on a generalised visual image which they speak of as a 'shape', a 'pattern' or a 'snake'. They do not generally pay much attention to forming images of the individual items but try to retain some version of the spatial pattern at the focus of conscious attention. The individual items (e.g. digits) can be retrieved separately and distributed along the 'snake' like familiar items on a washing line. Most subjects report that their retained visual image is in the form of a 'shape' which they use during verbal recall to describe the locations of the digits by generating sentences from this mental 'shape'. Subjects usually complain of having difficulty in recalling the most recent items because the 'shape' begins to fade away during this sentence generation process (crossing the A-L bridge). The retained visual image is mostly described as comprising a 'shape' or a 'line' in which the bends indicate the changes of direction rather than a complete matrix with numerals placed in their designated cells. This might suggest that the use of the digits is redundant. Also, this might suggest that a more direct method of visual recall would be to simply ask subjects to draw this *shape* or *'snake'* as they see it in their imagination. A new version of the task would thus eliminate the requirement to recall the individual items whilst providing the subject with essential information about the spatial pattern.

Therefore, a purified and simplified version of the Brooks Matrix would involve no generation or switching processes and no use of numerals. Such task would involve direct visual encoding by presenting the pattern TBR as spatial directions with each display showing a symbol that indicates the *direction* of the path within the matrix. Recall would also be direct by asking subjects to simply draw a line on a real matrix representing the 'pattern' as they see it in their imagination. Unlike other methods of recall such as verbal recall or visual recall by arranging cards on a matrix, this modified method of visual recall should reveal the information stored in the VSSP with minimum contamination by unnecessary processes. With this pure version of the task, which qualifies as a route 2 experiment within Annett's diagram, it may be possible to examine whether concurrent movement at encoding or during image maintenance actually interferes with the VSSP with the minimum of contamination by the CE or by verbal processes.

However, before such a variant is used, some preliminary work was needed to establish whether the SB task is significantly altered by dispensing with the digits which are presumably redundant. Dispensing with the digits also means not using the Brooks sentences which instruct subjects to place them in their designated squares. Instead, the pattern TBR would be presented aurally as a series of statements involving merely the directional adjectives (up, down, left, right).

Performance on this version could then be compared to performance on the standard Brooks Matrix task. If no significant change occurred, then the "purified" visually presented and recalled variant could be devised and examined in order to establish its characteristics prior to using it as a primary visuo-spatial task within a movement interference paradigm. The proposed new recall method which involves drawing the retained image on a real matrix should thus be examined in order to test its effects on performance. The new shortened "nondigital" variant of the Brooks Matrix along with its purified visually presented and recalled version could then be used to examine some hypotheses regarding the interference effects of some spatial and CE secondary tasks and hence to hopefully shed some light on the role of movement in the VSSP and the relationship between the controversial VSSP and CE components of WM.

5.2. Experiment III

5.2.1. Introduction:

Thus, the first condition of this experiment examined the suggested 'shortened' variant of the Brooks Matrix task in which the pattern TBR is presented as merely sequences of directional adjectives. It examined whether the standard Brooks task is significantly altered by dispensing with the digits and hence with the sentences which instruct subjects to place them within the 'mental' matrix. The new 'shortened' nondigital variant was both verbally presented and recalled. Performance was then compared to performance on the standard Brooks task in Experiment 1-a in which the task was also both verbally presented and recalled. After the 'validity' of this *shortened* variant has been established by showing that the use of the digits and thus the sentences is redundant, the methods of presentation and recall of this variant were then varied between verbal and visual modalities. The suggested method of visual or 'graphic' recall was examined which refers to subjects drawing a line on a real matrix representing the path as they see it in their imagination. Visual presentation refers to presenting the pattern TBR as a sequence of 8 successive displays of the matrix with each display showing the matrix with only one X at a time in the designated square through which the path is moving. Verbal presentation, on the other hand, refers to aurally presenting the pattern TBR as a sequence of 8 statements that merely comprise directional adjectives (starting square, up, left, etc.) and which describe a path within the matrix. Verbal recall refers to repeating verbatim the 8 statements or, as occurs when the task is visually presented, constructing the 8 statements from the retained mental image of the path. This variation in the encoding and decoding modalities resulted in an additional three conditions. As such, in this experiment there were four conditions or input-output combinations (Verbal-Verbal; Verbal-Visual; Visual-Verbal; and Visual-Visual).

Eight different subjects were tested under each condition. Subsequent to testing, subjects answered the VVIQ (see chapter 2 & Appendix 1.2). Subjects' ratings on the VVIQ were correlated to their performance on the 'shortened' Brooks task in order to examine whether vividness of visual imagery correlates with performance under each of the four input-output combinations. The following is a description of each of these 4 conditions:

Condition 1. Verbal input-Verbal output:

This first condition investigated the effects of dispensing with the digits, and thus with the Brooks sentences, on performance of the Brooks Matrix task. Results of the previous experiments have shown that subjects usually report that their retained visual image principally comprises a shape or a line in which the bends indicate the changes of direction, rather than a complete image of the matrix with the digits placed in their designated squares. This may suggest that the use of numerals, and thus sentences that describe their locations, is redundant. Hence, performance should not be altered due to the removal of the digits and thus presenting the pattern as only a series of spatial adjectives. However, recall may be insignificantly more efficient due to the expected shorter response time that will result from dispensing with the digits. Subjects will now only recall the spatial adjectives instead of complete sentences that describe the locations of the digits within the matrix. The retained visual image may thus be less prone to decay during retrieval. In Experiments I&II, some subjects reported that the 'shape' begins to fade away during sentence generation (reading off the image) which might explain the higher error rate at the last few items.

Hence, this condition examined the first possible manipulation in the modes of presentation and recall of this 'shortened' variant. The task was presented verbally as merely sequences of 8 spatial directions (e.g. Starting square, down, left etc.) instead of the SB sequences (e.g. in the starting square put a 1, in the next square down put a 2). The task was also recalled verbally by simply repeating back the spatial directions. No matrix was present at encoding or decoding. Thus, the standard Brooks procedure was followed except in regard to dispensing with the digits and the standard sentences.

It was hypothesised that presenting the task material aurally as merely spatial adjectives will not significantly alter the characteristics of the Brooks task since the use of digits is assumed to be redundant. Task difficulty should not also be altered under this input-output combination (verbal-verbal) because the task still requires both image generation at verbal input and the generation of a verbal output from a retained image. Within the proposed process model, the CE is required during the *verbal* encoding to switch between the external verbal input and the internal memory input (image generation from LTM upon hearing the statements). The CE is also involved during the *verbal* retrieval to generate the statements from the retained visual image. Within the ALI model (Annett, 1982; see figure 1.6) the task under this combination requires translations between the *action* and *language* systems. During verbal encoding, the task materials are initially encoded via the 'language system' and thus represented in the 'language representation' element of that system. This temporary representation is subsequently and rapidly translated into visual images and registered onto the sensory (action representation) element of the 'action system'. During verbal retrieval the task materials are then *translated* back to the sensory (language representation) element of the 'language system' and finally to the motoric (language production) element of that system for producing the verbal output. Hence, there is crossing and recrossing of the A-L bridge. Therefore, it is assumed that the task in this form is not suitable for examining the role of movement in the VSSP due to these presumably redundant processes.

The 8 tests (sequences of 8 sentences) used in the SB condition in Experiment 1-a were used after removing the digits and thus the sentences that instruct subjects to place them within the matrix. Performance was then compared to performance on the SB condition in Experiment 1-a. In that experiment, both presentation and recall were **verbal** and there were two conditions, the SB and the PB. To avoid practice effects, performance in this condition was only compared to performance of the 8 subjects who took the SB condition first. Thus, 8 subjects were tested using the shortened 'nondigital' Brooks Matrix tests. Performance was then compared to performance of the 8 subjects who were given the SB task first in Experiment 1-a in order to find out whether the task had been altered by this variation.

Condition 2. Verbal input-Visual output:

This second condition examined the suggested method of visual recall and its effect on performance of the current variant of the Brooks Matrix. Most subjects in the previous experiments reported that their visual image comprises principally a pattern or a snake-like shape in which the bends indicate the changes of direction rather than a complete matrix with numerals placed in the cells. Hence, a more direct decoding method would be to ask subjects to simply draw the "snake" as they see it in their imagination. Thus, this condition examined the second possible input-output combination. The 'shortened' variant was presented aurally as in Condition 1. However, unlike Condition 1 in which the task was recalled by repeating the 8 statements, in this condition the subject was presented with a real matrix at recall and was asked to simply draw a line representing the described path as they see it in their imagination.

It was predicted that performance under this input-output combination (verbal-visual) will not be better than performance in Condition 1 (verbal-verbal) since the results of Experiment (I) showed that the positive effects of the presence of the matrix were restricted to encoding rather than decoding. That is, the elimination of the image generation element at input leads to superior recall. Within the proposed process model, the CE is still required during aural input as in Condition 1. The CE involvement during the direct visual decoding has presumably been minimised since there is no generation of verbal output from the visual image. Within Annett's ALI model, the crossing of the A-L bridge is still required during aural encoding as in Condition 1. During visual decoding there is no longer a recrossing of the A-L bridge to translate the retained image into a verbal description. Instead, the task materials are now directly decoded by translating the visual information retained in the sensory element of the 'action system' into drawing through the motoric (action production) element of that system. As such, this variation is still not suitable for examining the nature of the VSSP due to the heavy CE involvement and the other verbal processes involved at aural encoding (the translation from the *language system* into the *action system*).

The method of visual recall used in this condition is different from the method of visual recall used in Experiments 1-b&d in which the task was recalled by arranging cards containing the digits on a real matrix. That method was found to be slightly less efficient despite the apparent direct decoding. This was probably because it required subjects to manipulate and sort the cards which were given to them in a random order. This manipulation of the cards might have interfered with the retained image. Thus a more direct method of visual recall would then be to simply ask subjects to draw the shape, as they see it in their imagination, on a real matrix. This method should reveal the contents of the VSSP with the minimum of contamination by other factors.

Condition 3. Visual input-Verbal output:

The aim of this condition was to examine the third possible variation in the modalities of encoding and decoding the 'shortened' variant of the Brooks Matrix task. The effect of visual presentation on performance of this variant was examined. The task was presented visually on a computer screen as sequences of 8 displays with each display showing only one symbol (X) at a time that indicates the square through which the path is moving. The task was however recalled verbally, as in Condition 1, by describing the image of the path within the matrix using 8 statements with the following structure: starting square, up, left, etc. Subjects were thus supposed to retain a mental image of the path and then read off that image by generating the 8 statements.

It was predicted that performance under this input-output combination would be superior to performance in Conditions 1&2 in which encoding was verbal. Experiments I&II have shown that visually, as opposed to verbally, encoding the SB task brings about a significant improvement in performance. The elimination of the image generation component of the task and the translation of information from the verbal system into the visuo-spatial system has been shown to lead to superior recall. Within the proposed process model, the CE involvement should be minimised as a result of visual encoding. No switching of attention is required at encoding since no image generation from LTM is needed. Instead, task materials are now encoded directly onto the visual buffer. In Conditions 1&2, in which this variant was presented verbally, the CE was assumed to be heavily involved during verbal encoding. In terms of Annett's ALI model (see figure, 1.6), with visual encoding there is no crossing of the A-L bridge. The task materials are now encoded directly onto the sensory (action representation) element of the 'action system'. In Conditions 1&2, the aurally presented task is initially encoded via the 'language system' with subsequent and rapid translation of information into the 'action system'. In this condition, that redundant process of crossing the A-L bridge is eliminated by the visual encoding of information through the 'action system'.

Thus, the *shortened* variant is now directly encoded onto the visuo-spatial buffer (VSSP). However, the task is presumably still not a pure visuo-spatial task since there is still CE involvement at decoding to generate verbal descriptions from a retained visual image. Within Annett's model, there is still crossing of the A-L bridge to translate the image retained in the 'action system' into the *language representation* element of the 'language system' to be then produced as verbal statements by the motoric (*language production*) element of that system. That is, there is still a need to turn an 'action' representation into words.

Condition 4. Visual input-Visual output:

This condition examined the last possible manipulation in the modalities of presentation and recall of the 'shortened' variant of the Brooks Matrix. The task was presented visually as in Condition 3 and was also recalled visually as in Condition 2. Subjects simply drew a line representing their visual image of the 'path' around the matrix as shown on the computer screen. It was predicted that performance under this input-output combination, in which no verbal or CE processes are involved, would show the largest reduction in error rate which should be superior to performance in Conditions 1&2 in which the task was aurally encoded. Performance should not be different from performance in Condition 3, in which presentation was visual, since the previous experiments which examined the SB task showed that the positive effects of the presence of the matrix are restricted to the encoding stage. However, with this version, a low error rate might occur. Thus, task difficulty should be examined and if necessary a 5x5 matrix could be used instead of the 4x4 matrix in order to make the task more difficult.

Within the proposed process model, this form of the task has presumably been purified from all heavy CE processes. There is no need for a heavy CE involvement at encoding or decoding. Unlike verbal presentation, with visual presentation there is no switching of attention between verbal input and image generation from LTM. Also, at visual decoding no generation of verbal output from a retained visual image is required. Within Annett's ALI model, there is no crossing or recrossing of the A-L bridge. The task now only involves the *'action channel'* and there is no longer any communication with the *'language channel'* (see figure 1.6). The task now is directly encoded onto the *action representation* element of the *'action channel'* and directly decoded by the *action production* element of that channel of the cognitive system as conceptualised by Annett (1982, see chapter 2).

Hence, this form of the task does not have a verbal component and should not require the involvement of the AL or the CE in its processing. As previously indicated, Morris (1986a) argued that a major problem with the early Baddeley experiments was that all tasks used have a large verbal component. The spatial tasks used require initial verbal encoding with transformation into spatial representations. This implies that the stimuli must first be represented in the central processor with subsequent rapid registration onto the Sketch Pad. Also, Quinn (1990) indicated that many experiments showing interfering effects in the VSSP have arguably confounded their interpretation by failing to control CE effects. More recently, Wang & Bellugi (1994) indicated that a variety of tasks has been employed for the assessment of the VSSP. Many of these tasks, including of course the Brooks Matrix, incorporate the confounding task of constructing a mental image from verbal input. Such criticisms should not apply to this visually presented and recalled version of the Brooks Matrix task.

This final version is assumed to be the purest visuo-spatial form of the Brooks task which will enable examining the role of movement in the VSSP. It should enable examining whether movement interferes because both tasks require a common

WM resource, and if so what is the nature of that resource? Is it a representation of space, or is it perhaps the involvement of the hypothetical CE? All of the redundant codes and processes have been removed. No contamination or confounding by CE and verbal processes is expected, and this version should enable examining whether a dissociation between the CE and the VSSP is possible.

5.2.2. Method

A) Material & equipment

1) For Condition 1:

The same material used for the SB condition in Experiment 1-a were used. The same 8 Brooks tests (see Appendix 2.2) were used after removing the digits and hence the sentences. These tests were therefore presented as merely sequences of spatial directions. For instance, test 2 which was presented as:

In the starting square put a 1.
In the next square **up** put a 2.
In the next square to the **left** put a 3.
In the next square **down** put a 4.
In the next square **down** put a 5.
In the next square to the **right** put a 6.
In the next square **down** put a 7.
In the next square to the **left** put an 8.

was presented in this condition as:

Starting square
Up
Left
Down
Down
Right
Down
Left.

Apart from this change of replacing the standard sentences with short statements comprising merely the spatial adjectives, no other modification was introduced to the task. The modified sequences were presented using a male voice at the rate of 1 statement per 2.5 seconds following the same procedures used in Experiment 1-a. These shortened tests were recorded on an audiocassette for use with all subjects. Subjects' responses were simultaneously hand-recorded by the experimenter on A4 sheets, each containing 6 small matrices, by writing down a symbol that represents the spatial direction within the matrix as recalled by the subject. Responses were also tape-recorded in order to double-check the accuracy of the hand-recording. The same equipment and procedures used for the SB condition in Experiment 1-a were thus used with slight modifications to suit the change from the standard version into the 'shortened' version.

2) For Condition 2:

The same material and equipment used in Condition 1 were used. The only difference is related to the method of recall. A 'recall sheet' containing a 4x4 square matrix (10x10cm) was used for drawing the image of the path. The starting square was marked with a cross. A pen was provided for drawing the image. A new recall sheet was used for every trial. As in Experiments 1-b&d, subjects' responses were video-taped using the same equipment (video camera, VCR, & a video-monitor).

3) For Condition 3:

The same 8 'shortened' Brooks tests and material used in Condition 1 were used with some modification to suit the change from verbal into visual presentation. This modification was as follows: the 8 tests were presented visually on a computer screen using the application HC. Each test (sequence of 8 statements) was presented as a sequence of 8 displays on a computer screen at the rate of 1 display per 2.5 seconds. This was accomplished by the following procedure:

A 2.1 HC application on a Macintosh Plus computer was used. A 4x4 square matrix (10x10cm), with no starting square marked, was drawn using the application SuperPaint and was then *pasted* on a card. The card was then *copied* into 8 cards for making the first test. Then the first shortened Brooks test, which comprises the following 8 statements: *Starting square, Left, Up, Right, Right, Down, Down, Right,* was transformed into 8 different 'hyperCards' as follows: the first card showed the matrix with an X in the **starting square**; the second card showed only an X in the square to the **left** of the starting square; the third card showed only an X in the square **above** the previous square; the fourth card showed only an X in the square to the **right** of the previous square; the fifth card showed only an X in the square to the **right** of the previous square; the sixth card showed only an X in the square **below** the previous square; the seventh card showed only an X in the square **below** the previous square; and the eighth 'hyperCard' showed only an X in the square to the **right** of the previous square.

Hence, each card showed the matrix with only one symbol (X) in the centre of the successively designated square through which the path is moving. The 8 cards of the first test were presented at the rate of 1 card per 2.5 seconds. This was accomplished by creating a HC button on a blank 'hyperCard'. This button was named 'Test 1' and scripted (programmed) to, when clicked on, present the first card then wait 2.5 seconds and then present the second card and so on until the ninth card (a blank card) is displayed. The HC script is shown in Appendix 4.1. Thus, to present 'Test 1' of the Brooks tests, one just needs to hold the 'mouse' and click on the 'test 1' button and this will automatically lead to the 8 'hyperCards' being presented at the rate of 1 card per 2.5 seconds. As can be seen in the script, the button was programmed to stop at card# 9. Card# 9 comprises only a blank card so that during recall, the computer screen contains only this empty card in order to avoid any distraction. Card# 9 was a blank card with the exception of a very small arrow which, if clicked on, will lead to the next card (10) being displayed. Card 10 contains a button named (Test 2). Test 2 was presented following the same procedure used in presenting Test 1. The script for the button 'Test 2' is shown in Appendix 4.1. The procedure, which was followed in visually presenting the first two tests using HC, was followed in presenting the other six 'shortened' Brooks tests.

Recall was verbal by describing the *direction* of the path within the matrix. Subjects' responses to the 6 testing trials were thus recorded using the same equipment as in Condition 1.

4) For Condition 4:

For presentation of the task, the same equipment and material used to visually present the task in Condition 3 were used. Recall was also visual as in Condition 2. The same material and equipment used for visual recall in Condition 2 were used.

B) Subjects:

Eight different subjects were recruited for each condition from undergraduate and postgraduate students at Warwick University. Thus, a total of 32 subjects took part in this experiment. Subjects were tested individually and each was paid a fee of £1.50. None had taken part in any of the previous experiments.

For Condition 1, The 8 subjects were 4 males and 4 females. Their age ranged from 19-47 with a mean of 26. For Condition 2, the 8 subjects were 5 males and 3 females. Their age ranged from 19-28 with a mean of 21. For Condition 3, the 8 subjects were 5 males & 3 females. Their age ranged from 20-24 with a mean of 21.5. For Condition 4, the 8 subjects were 5 males & 3 females. Their age ranged from 19-34 with a mean of 22.6.

C) General procedure:

1) For Condition 1 (verbal-verbal):

The same procedures used in the SB condition in Experiment 1-a were used after making some modifications in the introduction and instructions to suit the change from using the standard sentences into using merely spatial directions. The subject was initially introduced to the task and was shown a 4x4 matrix (10x10cm) with the starting square marked. Then, the subject was informed that he (she) was to visualise the matrix while listening to a set of 8 short statements describing a path around the squares of the matrix. It was indicated that the statements were of the sort "Starting square, Up, Left, etc.". Subjects were shown how these statements related to the matrix and were informed that tests (sets of 8 statements) differed only in regard to the *directions* of the path described around the matrix. It was pointed out that each sequence of 8 statements will always begin from the same starting square. Subjects were informed that during testing the matrix will not be present at input or output and that they are supposed to rely on forming an image of the spatial directions in the form of a path within the squares of the matrix.

Subjects were instructed to repeat the 8 statements after the last statement had been presented. They were instructed to attempt to remember the statements by forming a mental image of the *direction* of the path within the squares of the matrix. They were informed that this image could then be used at recall to help in reconstructing the eight statements.

In this condition no digits were used which usually act as a cue for the subject during retrieval to recall the locations until the location of the last digit is described. In the previous experiments, subjects often keep on recalling until the location of the last digit (8) has been recalled or even guessed. Recalling the location of the digit 8 is considered by subjects as the indicator to end the recall process even if the correct location cannot be retrieved from visual memory and thus the subject might just guess the location. In this condition, this cue is no longer available to the subject to indicate the end of the recall process. A pilot subject was tested prior to testing and it was observed that when the subject had a problem during recall and thus was not sure of how many spatial directions have or have not been recalled, she was waiting for the experimenter to indicate whether or not all of the 8 statements had been recalled. Therefore, during testing each subject was instructed to indicate that he (she) has finished recall by saying the word 'finished'. The aim of this was to prevent the subject from waiting for any indication from the experimenter regarding whether or not all of the 8 statements had been recalled. All other testing procedures were the same as those used in the SB condition in Experiment 1-a. These include the presentation rate and the tape-recording of responses for subsequent analysis.

2) For Condition 2 (verbal-visual):

In this condition, the 'shortened' Brooks task was presented verbally and was recalled visually. Thus, the same procedures and instructions used for presentation of the task in Condition 1 were used. These included the initial introduction of the task to the subject and the imagery instructions. Regarding the imagery instructions, subjects were informed that during testing no matrix will be present at input and that they should attempt to remember the path by forming a mental image of the directions given in the 8 statements. They were informed that this image could then be used to help recall the path.

Changes were only introduced to the recall procedure and instructions to fit the change from verbal into visual recall. Subjects were informed that after all of the 8 statements had been presented, they will be presented with a 4x4 matrix and a pen and that the task will be to draw a line on the matrix representing their mental image of the path which had been described by the statements. They were informed that their responses will be video-taped for subsequent analysis.

3) For Condition 3 (visual-verbal):

The procedure followed in Condition 1 was followed with some modification to suit the change from verbal into visual presentation. The subject was initially introduced to the task. He (she) was shown a 4x4 matrix with the starting square marked with a cross. Then the subject was informed that he (she) will be required to watch a set of 8 consecutive displays of the matrix on the computer screen that show a path around the squares of the matrix. It was pointed out that the path always began from the same starting square (the second cell on the second row). Subjects were shown how the 8 displays related to the matrix. It was indicated that the first display will always show an X in the starting square whereas the other 7 displays will show the same X moving successively in adjacent squares around the matrix. It was explained that the only way in which tests (sequences of 8 displays) differed was the sequence of transitions (up, left, down, right) from one square to another.

Subjects were instructed to verbally describe the path after all of the 8 displays had been presented, by constructing 8 statements with the following structure: **Starting square, Up, Down, Right, ...**and so forth until the eighth square at which the path stopped has been described. They were instructed to attempt to remember the 8 displays of the matrix by forming a mental image of the path within the squares of the matrix. They were informed that this image could then be used to help in recalling the path by constructing the 8 statements. The same procedures used for verbal recall in Condition 1 were used in this condition.

4) For Condition 4 (visual-visual):

The same instructions and procedures followed in Condition 3 to visually present the task were followed in this condition. These included the initial introduction of the task to the subject and the imagery instructions. Also, the same instructions and procedures followed in Condition 2 to visually recall the task were followed here with minor modifications to suit the current manipulation. Subjects were informed that the task is to recall the path by drawing it on a real matrix. They were instructed that after presentation of each test (sequence of 8 displays) they will be presented with a 4x4 matrix and a pen and that the task is to draw a line on the matrix representing their mental image of the path which has been shown. Subjects were instructed to attempt to remember the path by forming a mental image of the *direction* of the path within the matrix. They were informed that this image could then be used to help in recalling (drawing) the path.

D) Experimental design & set-up:

A between subjects independent groups design was used as performance of the 8 subjects in Condition 1 was initially compared to performance of the 8 subjects who were given the SB condition first in Experiment 1-a. Then performance of each group of subjects in each condition of this experiment was compared to performance of the other groups. Therefore, the 4 conditions of this experiment were treated as a 2(encoding modality) x 2(decoding modality) unrelated design. In each condition, subjects were given 6 experimental trials. The experimental set-up and the testing steps for each of the 4 conditions of this experiment were as follows:

1) Condition 1 (verbal-verbal):

The experimental set-up was identical to that of Experiment 1-a. After the initial introduction to the task, each subject was given 2 practice trials followed by 6 experimental trials. The first 2 tests (sequences of 8 spatial directions) were always used for the 2 practice trials whilst the other 6 tests were used for the 6 testing trials. During the first practice trial, the subject was presented with the 4x4 square matrix (10x10cm) with the starting square marked with a cross and asked to listen to the first sequence of 8 spatial directions (test 1) and to repeat verbatim the sequence after all of the 8 statements were presented and the diagram was removed. Then a second practice trial was given using the second test without the matrix being present at input or output.

After this practice period, each subject was given 6 testing trials during which no diagram was present at input or output. Thus, the procedure used in this condition was identical to the procedure used with the SB condition in Experiment 1-a apart from using sequences of merely spatial adjectives instead of the standard Brooks sentences, and thus slightly modifying the introduction and the instructions of the task to suit this variation.

2) Condition 2 (verbal-visual):

The same experimental set-up used in Condition 1 was used here with one modification related to the recording of responses. The video-camera was installed on a tripod at the right hand-side of the subject so that it overlooked the subject when they drew their mental image of the path on a real matrix. The VCR and the video-monitor were placed within the reach of the experimenter so as to be able to operate and monitor the recording of responses. Only one tape-recorder was placed on the table for presenting the task. A photograph illustrating the experimental set-up, with the subject visually decoding the task, is provided in Appendix 4.2.

After the initial introduction to the task, each subject was given 2 practice trials followed by 6 experimental trials using the same 8 tests used in Condition 1. The first two tests were always used for the 2 practice trials. During the first practice trial, the subject was presented with the 4x4 matrix with the starting square marked and was asked to listen to the first test (sequence of 8 statements). The matrix was placed on the table in front of the subject who was reminded that after listening to all of the 8 statements, the task was to draw a line on the matrix representing his (her) mental image of the path which has been described. Then a second practice trial was given using the second test without the matrix being present at input. Thus, in this second practice trial, the subject had to rely on his (her) mental imagery during aural input to *generate* an image that represents the path. Then, at recall he (she) was presented with a new recall sheet and asked to draw a line on the matrix representing their mental image of the path. After this practice period, each subject was given 6 testing trials using the remaining six tests. During this testing no matrix was present at aural input but, of course, a new matrix was always presented at output for recall by drawing.

3) Condition 3 (visual-verbal):

The testing steps followed in Condition 1 were followed with some modification to suit the change to visual presentation. Testing took the following form:

The subject was seated at a rectangular table. The experimenter sat at the end of the table which is on the left handside of the subject so as not to be facing the subject. In front of the experimenter a 30cm-high x 45cm-wide stand was placed on the tabletop in order to hide the test material (e.g. matrices) from the subject's sight. The computer used to present the task was placed on the table facing the subject, approximately 0.60 metre away from the subject. The 'mouse' was placed within the experimenter's reach so as to be able to operate the presentation of the tests (the 8 sequences of 8 displays). The tape-recorder was placed on the table for recording subjects' responses as in Condition 1. An illustration of the experimental set-up, with the subject visually encoding the task, is provided in Appendix 4.2.

After the initial introduction to the task, the subject was given 2 practice trials followed by 6 experimental trials. The first two 'tests' were always used for the 2 practice trials whereas the other 6 tests were used for the 6 testing trials. During the first practice trial, the subject was asked to watch the first sequence of 8 displays on the computer screen which showed a path around the squares of the matrix. The subject was informed that after the 8 displays had been shown, the task will be to describe the *direction* of the path by constructing 8 statements with a specific structure as was explained in the procedure section. No matrix was present at recall. The subject was supposed to maintain a mental image of the path shown by the 8 displays and use that image at recall to help in describing the path. Then a second practice trial was administered followed by 6 testing trials using the same procedure.

4) Condition 4 (visual-visual):

The experimental set-up was the same as in Condition 3 with one modification to suit the change from verbal into visual recall. No tape-recorder was used since recall was visual. Instead, Subjects' responses, in which they drew their images on real matrices, were video-taped for subsequent analysis. A video-camera was installed for this recording exactly as in Condition 2 (see Appendix 4.2).

After the initial introduction of the task, the subject was given 2 practice trials followed by 6 testing trials using the same 8 tests (sequences of 8 displays) used in Condition 3. The first two tests were always used for the two practice trials and the other six tests were used for the 6 testing trials. In the first practice trial, the subject was asked to watch the first sequence of 8 displays of the matrix on the computer screen which showed a path around the squares of the matrix. After the 8 displays had been shown, a real matrix was placed in front of the subject whose task was to draw a line on the matrix representing his (her) mental image of the path which had been shown. Then a second practice trial was administered followed by 6 testing trials using the same procedure.

In each of the above four conditions, no limit was imposed on response time and subjects were made aware of this and of the recording of responses. For each condition, a specific and unified set of instructions was used with all subjects (see Appendix 4.3).

5.2.3. Results

For conditions 1&3, in which recall was verbal, performance was measured by the number of statements that were correctly recalled. Errors were counted for each subject and an error here refers to any statement (spatial adjective) that was incorrectly recalled or constructed. In each trial, 8 statements had to be recalled or constructed. The first statement involved no spatial adjective and was always the same (Starting square) and thus involved no errors. There are therefore 7 possible errors in each trial and since each subject was given 6 experimental trials, there are 42 possible errors per subject in each condition.

For conditions 2&4, subjects responded by drawing a line on a real matrix representing their mental image of the path described by the 8 statements (shown by the 8 displays). Each line drawn on the matrix started from the starting square and changed direction according to each sequence of 8 *spatial directions*. Thus, any bend in the line which does not match its corresponding *spatial direction* was considered an error. Errors were counted for each subject and an error here refers to any incorrect bend in the line drawn on the matrix. Each bend in the line drawn represents one of the 8 directions (e.g. up, left) respectively. In each trial, 8 items had to be recalled. The first involved no *spatial direction* and was always the same starting square and thus involved no error. There are therefore 7 possible errors in each trial and since each subject was given 6 experimental trials, there are 42 possible errors per subject in each condition.

The results were as follows:

1) Initially performance of the 8 subjects in Condition 1 was compared to performance of the 8 subjects who were given the SB condition first in Experiment 1-a in order to find out whether the Brooks Matrix task had been altered by dispensing with the use of the digits and presenting the pattern TBR as merely a sequence of directional adjectives. Table 5.a shows the mean percentage of error in both of these two conditions and figure 5.1. illustrates these data:

Condition	Mean	N	SD
Standard version(Experiment 1-a)	18.76	8	20.19
Shortened version(Condition 1)	15.48	8	9.10

Table 5.a. Mean percentage of errors made at the standard version and the shortened 'nondigital' version of the Brooks Matrix task.

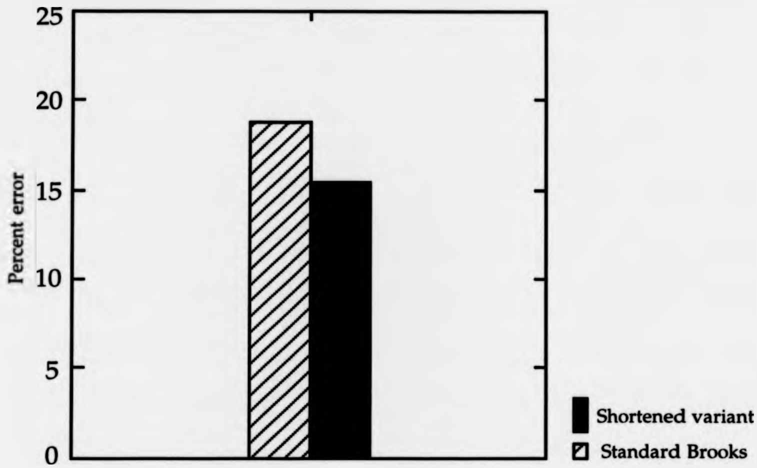


Figure 5.1. Mean percentage of error at the standard and the 'shortened' versions of the Brooks Matrix task.

Performance on the new non-digital variant was compared to performance on the standard Brooks task. An independent samples t-test with task-version as the grouping factor was performed on this data and showed no significant difference (t=0.42, df=14, p=0.68). The two versions appear to be at similar levels of difficulty.

2) Performance of the task under each condition in this experiment was compared to performance under the other conditions in order to find out the effect of each input-output combination on performance of the current 'shortened' variant of the Brooks Matrix. Table 5.b. shows the mean percentage of error under each condition in this experiment and figure 5.2 illustrates these data:

Condition	Mean	N	SD
1 Verbal-Verbal	15.48	8	9.10
2 Verbal-Visual	13.40	8	9.08
3 Visual-Verbal	6.86	8	5.31
4 Visual-Visual	5.95	8	8.45

Table 5.b. Mean percentage of error under each condition (input-output combination) in this experiment.

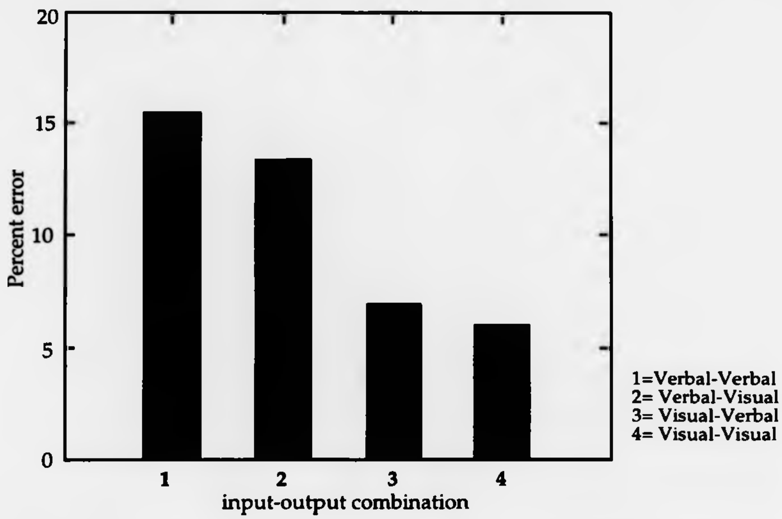


Figure 5.2. Mean percentage of error on the 'shortened' version of the Brooks Matrix under each input-output combination (condition).

First, the above data, shown in table 5.b and figure 5.2, were analysed by treating the four conditions as a 2(encoding modality) x 2(decoding modality) unrelated design and thus a two-way unrelated ANOVA was conducted on the data. Encoding and decoding modalities were the independent variables and each has 2 levels (verbal & visual). Errors were the dependent variable. This ANOVA showed a highly significant main effect of encoding modality [$F(1,28)=7.81$, $p=0.01$]. Visual encoding led to superior performance in comparison to verbal encoding. There was no significant main effect of decoding modality [$F(1,28)=0.27$, $p=0.61$]. Visual decoding is no better than verbal decoding. There was no interaction between encoding modality and decoding modality [$F(1,28)=0.04$, $p=0.84$].

Second, in addition to the ANOVA, individual comparisons among the four conditions were conducted as follows:

Performance in Condition 1 (verbal-verbal) was compared to performance in Condition 2 (verbal-visual) in order to find out if the manipulation in the method of recall brought about any significant change in performance. The mean percentage of error in Condition 1 was 15.48 whereas it was 13.40 in Condition 2. An independent samples t-test, with condition-type as the grouping factor, was performed on the data of both conditions and showed no significant difference ($t=0.46$, $df=14$, $p=0.65$). Visually recalling the task by drawing the retained image on a real matrix led to no significant improvement in performance. When the task is verbally encoded, changing the method of decoding from verbal into visual does not lead to a change in performance.

Performance in Condition 3 (visual-verbal) was compared to performance in Condition 1 (verbal-verbal) in order to find out if the manipulation in the modality of presentation brought about any significant change in performance. The mean percentage of error in Condition 3 was 6.86 whereas it was 15.48 in Condition 1. A similar independent samples t-test was performed on this data and showed a significant difference ($t=2.32$, $df=14$, $p=0.04$). Changing the method of presentation from verbal into visual brought about a significant improvement in performance of the 'shortened' variant of the Brooks task. Performance in Condition 3 (visual-verbal) was also compared to performance in Condition 2 (verbal-visual). The mean percentage of error in Condition 3 was 6.86 whereas it was 13.40 in Condition 2. A similar independent samples t-test just failed to show a significant difference ($t=1.76$, $df=14$, $p=0.10$).

Performance in Condition 4 (visual-visual) was compared to performance in Condition 1 (verbal-verbal) in order to find out if the manipulation in both modalities of input and output brought about any significant change in performance. The mean percentage of error in Condition 1 was 15.48 whereas it was 5.95 in Condition 4. A similar independent samples t-test was performed on this data and showed a significant difference ($t=2.17$, $df=14$, $p=0.048$). Visually encoding and decoding the task brought about an improvement in performance in comparison to verbally encoding and decoding the task. Performance in Condition 4 (visual-visual) was also compared to performance in Condition 2 (verbal-visual).

The mean percentage of error in Condition 2 was 13.40 whereas it was 5.95 in Condition 4. An independent samples t-test just failed to show a significant difference ($t=1.70$, $df=14$, $p=0.11$). Finally, performance in Condition 4 (visual-visual) was compared to performance in Condition 3 (visual-verbal). The mean percentage of error in Condition 3 was 6.86 whereas it was 5.95 in Condition 4. An independent samples t-test showed no significant difference ($t=0.25$, $df=14$, $p=0.80$). Combining visual decoding with visual encoding led to no change in performance in comparison to performance under visual encoding-verbal decoding. As long as the task is visually encoded, performance remains the same whether the task is verbally or visually decoded.

<u>VVIQ:</u>

As indicated above, in each condition subjects answered the VVIQ subsequent to testing. The total VVIQ scores of the 8 subjects in each condition were correlated to the numbers of errors they made on the 'shortened' version of the Brooks Matrix task in that condition. Since the size of sample in each condition is small (8 subjects) and probably does not meet the parametric assumptions, a Spearman correlation test was performed on the data in each condition. The results were as follows: For Condition 1, there was no significant correlation between ratings on the VVIQ and performance on the 'shortened' verbally presented and recalled version of the Brooks Matrix task ($rho=0.12$, $p>.05$). For Condition 2, there was no significant correlation between ratings on the VVIQ and performance on the 'shortened' version which was recalled visually by drawing the image ($rho=0.38$, $p>.05$). For Condition 3, there was no significant correlation between ratings on the VVIQ and performance on the 'shortened' version which was presented visually in this condition ($rho=0.20$, $p>.05$). For Condition 4, there was a nonsignificant negative correlation between ratings on the VVIQ and performance on the visually presented and recalled version ($rho=-0.32$, $p>.05$). This latter result is unexpected since it means that the more vivid visual imagery is, the more errors are committed. The prediction was that ratings on the VVIQ should show stronger correlation with performance in Condition 4 since the visually presented and recalled version of the Brooks is assumed to be the purest visuo-spatial version that should rely more on the VSSP and visual imagery for its performance. However, this result must be considered with caution since the sample is very small.

In addition, an overall correlation between performance of the 32 subjects tested under these four conditions and their ratings on the VVIQ was conducted. A Pearson correlation test showed no significant correlation ($r=-0.03$, $p=0.89$). These results of no correlation are consistent with previous findings in this study which have so far shown no significant correlations between ratings on the VMIQ or VVIQ and performance on the Brooks Matrix. A discussion of these results and of the relationship between subjective reports of imagery vividness and performance on visuo-spatial memory tasks is provided in section 5.3.

Serial position analyses:

An analysis of the SP effect was carried out on the data for each condition in order to find out the nature of the SP curves under the various input-output combinations and whether they differed or not. Errors made at each of the 8 serial positions (spatial directions) in each condition were counted. Eight subjects were tested in each condition and each was given 6 experimental trials. Therefore, in each condition, each position had 48 chances of being error. The SP analyses were as follows:

1) Initially, the SP curve of the *shortened nondigital* version obtained in Condition 1 was compared to the SP curve of the 8 subjects who were given the SB task first in Experiment 1-a in order to find out the nature of the SP curves for the two versions and whether they differed or not. Figure 5.3. shows the mean percentage of error at each SP under the standard and the 'shortened' versions of the Brooks Matrix task:

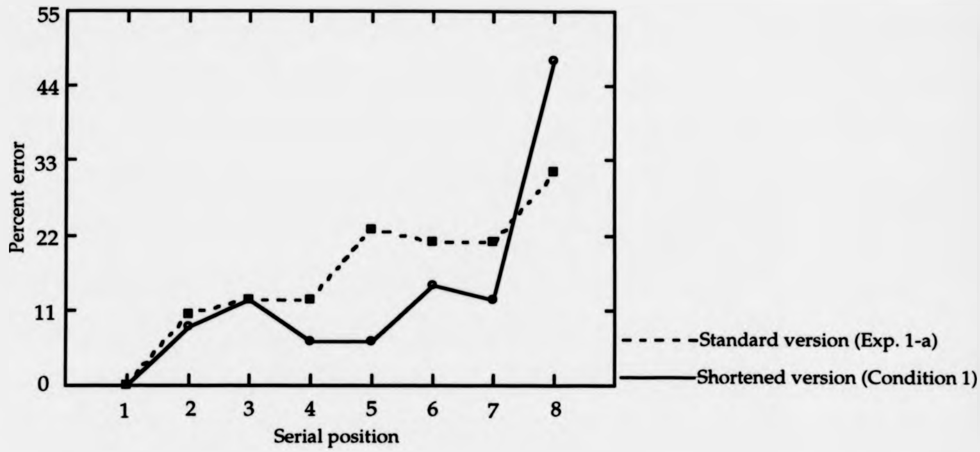


Figure 5.3. The SP curves for the standard and the'shortened' versions of the Brooks Matrix task.

As usual no errors were committed at the first SP since, in these two conditions, it was always the same statement (starting square) or the same sentence (in the starting square put a 1). Position 1 was thus excluded from the statistical analysis. A 2(task-version) x 7(positions) between subjects repeated measures ANOVA was performed on the SP data with task-version as the grouping factor and positions 2-8 as the repeated measures variable. The analysis showed no significant main effect of task-version [$F(1,14)=0.18$, $p=0.68$]. Similar numbers of errors were made under both versions of the task. There was a highly significant main effect of SP [$F(6,84)=10.81$, $p=0.00$]. More errors were made at some positions than others. The interaction between task-version and SP was also significant [$F(6,84)=2.62$, $p=0.02$]. The two curves are not parallel.

2) The SP curve obtained under each of the four conditions of this experiment was compared to its counterparts under the other conditions in order to examine whether the variation in the modalities of encoding and decoding led to different SP effects. The following three figures show the SP curves obtained under Conditions 2,3&4.

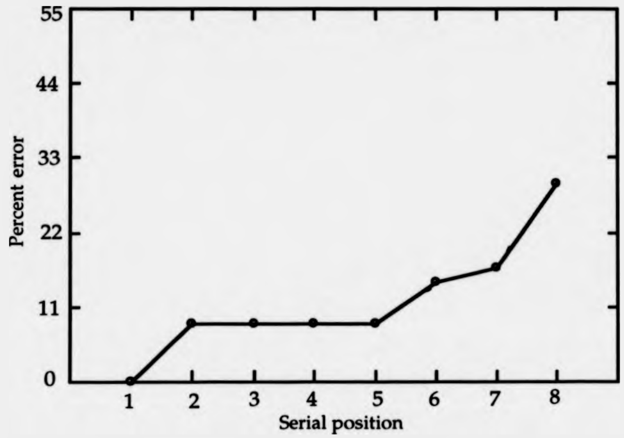


Figure 5.4. The SP curve obtained in Condition 2 (verbal input-visual output).

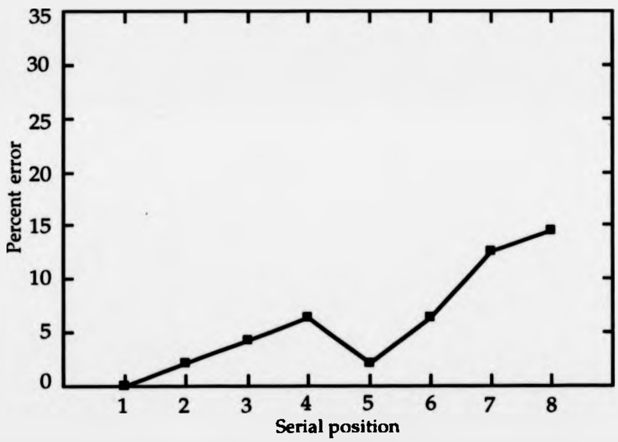


Figure 5.5. The SP curve obtained in Condition 3 (visual input-verbal output).

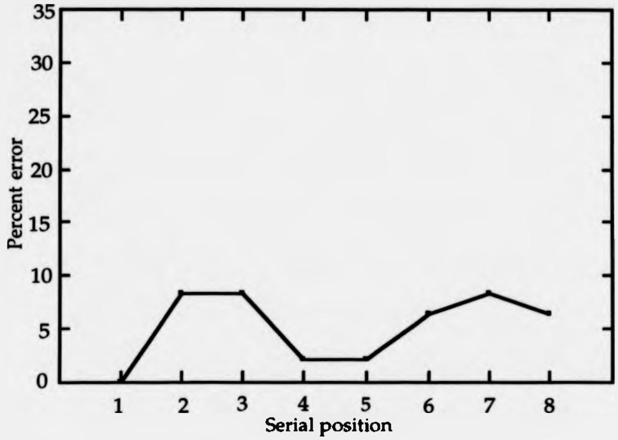


Figure 5.6. The SP curve obtained in Condition 4 (visual input-verbal output).

The SP curve obtained in Condition 2 (verbal-visual) was compared to the SP curve obtained in Condition 1 (verbal-verbal). The first serial position was excluded from the statistical analysis since it was always the same *starting square*. That is, no errors were ever made at the first SP since the path always began from the same starting square. Thus, a 2(conditions) x 7(positions) between subjects repeated measures ANOVA was performed on the SP data with condition-type as the grouping factor and positions 2-8 as the repeated measures variable. The analysis showed no significant main effect of condition-type [F(1,14)=0.21, p=0.65]. Similar numbers of errors were made under both conditions. There was a highly significant main effect of SP [F(6,84)=14.23, p=0.00]. In both curves, more errors were made at some positions than others. The interaction between condition-type and SP was nonsignificant [F(6,84)=1.76, p=0.12]. The SP curves for Conditions 1&2 appear to be parallel.

The SP curve obtained in Condition 3 (visual-verbal) was compared to the SP curve obtained in Condition 1 (verbal-verbal). A similar ANOVA showed a significant main effect of condition-type [F(1,14)= 5.38, P= 0.04]. More errors were made in Condition 1. There was a highly significant main effect of SP

[F(6,84)=10.99, p=0.00]. In both conditions, more errors were made at some positions than others. There was also a significant interaction between condition-type and SP [F(6,84)=4.13, p=0.00]. The SP curves for Conditions 1&3 are not parallel.

The SP curve obtained in Condition 3 (visual-verbal) was compared to the SP curve obtained in Condition 2 (verbal-visual). A similar ANOVA was performed on the SP data of both conditions and showed no significant main effect of condition-type [F(1,14)=3.10, p=0.10]. Conditions 2&3 did not significantly differ in regard to the overall error rate. There was a highly significant effect of SP [F(6,84)=9.15, p=0.00]. In both conditions, more errors were made at some positions than others. There was no significant interaction between condition-type and SP [F(6,84)=0.99, p=0.44]. The SP curves for conditions 2&3 are parallel.

The SP curve obtained in Condition 4 (visual-visual) was compared to the SP curve obtained in Condition 1 (verbal-verbal). A similar ANOVA was performed on the SP data of the two conditions and showed a significant main effect of condition-type [F(1,14)=4.72, p=0.048]. More errors were made in Condition 1 than in Condition 4. There was a highly significant main effect of SP [F(6,84)=7.10, p=0.00]. In both conditions, more errors were made at some positions than others. The interaction between condition-type and SP was also highly significant [F(6,84)=6.12, p=0.00]. The SP curves for Conditions 1&4 are not parallel.

The SP curve obtained in Condition 4 (visual-visual) was compared to the SP curve obtained in Condition 2 (verbal-visual). A similar ANOVA was performed on the SP data of both conditions and showed no significant effect of condition-type [F(1,14)=2.88, p=0.11]. Conditions 2&4 did not significantly differ in regard to the overall error rate. There was a highly significant effect of SP [F(6,84)=4.13, p=0.00]. In both conditions, more errors were made at some positions than at others. There was also a significant interaction between condition-type and SP [F(6,84)=3.14, p= 0.01]. The SP curves of Conditions 2&4 are not parallel.

Finally, in order to find out if the SP curve obtained in Condition 4 is different from its counterpart in Condition 3, a similar ANOVA was performed on the SP data of both conditions and showed no significant effect of condition-type [F(1,14)=0.06, p=0.80]. Similar numbers of errors were made in Conditions 3&4. There was a significant effect of SP [F(6,84)=2.39, p=0.04]. In both conditions, more errors were made at some positions than others. The interaction between condition-type and SP was not significant [F(6,84)=1.62, p= 0.15]. The SP curves of Conditions 3&4 appear to be parallel.

5.2.4. Discussion

The purpose of this experiment was to examine the proposed 'shortened' variant of the Brooks Matrix task in which no digits and thus no standard sentences were used. Instead, the pattern TBR was presented as sequences of merely directional adjectives. It was assumed that the use of the digits and sentences is redundant and hence the task should not be altered. Thus, Condition 1 examined this assumption by comparing performance on this variant to performance on the SB condition in Experiment 1-a. It was hypothesised that the task's nature and difficulty should not be altered since the task in this condition is verbally presented and recalled as in the SB condition. The same cognitive processes assumed, by the process model and the ALI model, to be involved in performance of SB task are still required.

Results supported this prediction. Subjects' performance did not differ from performance of subjects in Experiment 1-a who were given the SB task first. The mean percentage of error in the SB condition was 18.76 whereas it was 15.48 in Condition 1. Although there was some insignificant improvement, it should be noted that in the SB condition the SD was 20.19 which is much higher than its counterpart in Condition 1 which was only 9.10. In the SB condition the lowest number of errors made was 0 and the highest was 22 whereas in Condition 1 the lowest number of errors made was 2 and the highest was 12. Thus, there is more homogeneity of variance in the 'shortened' Brooks condition. In short, the task's difficulty was not altered. Presenting the pattern TBR as a series of up, down, left, right statements led to an error rate that is comparable to the error rate made under the standard "in the starting square put a 1, in the next square up put a 2,.." form.

Moreover, the cognitive processes and the processing strategies involved in performing the task do not appear to have been altered as a result of the introduced change. Each subject in Condition 1 was asked about his (her) comments regarding the difficulty of the task and the strategies used in its processing. The overwhelming majority of subjects indicated that the task was hard mostly due to the tendency to lose the mental image during aural input or when trying to read the items off that image. The comments made by subjects regarding the processing and difficulty of the task (see Appendix 4.4) are consistent with subjects' reports in Experiments I&II particularly those which involved conditions that used the same modalities of presentation and recall. Subjects still reported that the task was a hard task that requires concentration and image generation. The majority reported main reliance on forming a mental image to perform the task with the image mostly described as 'line' or a 'pattern' of the relevant squares and not a full 'picture' of the matrix or as one subject put it *"you can't visualise the grid itself, only parts of it with a pattern of squares that stands out"*. But, a few subjects reported using imagery that it is sometimes backed up by memorising words (e.g. up, left). Subjects also still reported that the end of the pattern is harder to maintain because it *'gets hazy'* and because they *'run out of span'* or as one subject put it *"It is good there were no more than 8 items because that is the maximum I can handle"*. Another reason is that the first few items are rehearsed more or as one subject put it *"it is easy to remember the first items because I 'saw' them in my mind the most but the end of the line tends to disappear because I only 'saw' it once"*. In addition, subjects usually indicate that some tests are easier than others. If a test involves adjacent squares in adjacent rows it becomes easier than otherwise.

Condition 2 then examined the second possible variation in the modalities of presentation and recall of this *shortened* variant. The task was presented verbally, as in Condition 1, but it was recalled visually using the suggested method of visual decoding (by drawing). Results showed that performance was not significantly better than performance in Condition 1 (verbal-verbal). In Condition 1, in which no matrix was present at recall, the total number of errors made was 52, 8 of which were made as a result of going outside the 'mental' matrix. Thus, about 15% of the errors were made outside the "mental" matrix. In Condition 2, in which only a total of 45 errors were made, a matrix was present at recall and thus there was no possibility of making any error outside the matrix. The difference between the total numbers of errors made in the two conditions is 7 errors (an improvement of 14%). Thus, it appears that the percentage of errors made outside the matrix as a mere result of no matrix being present (15%) is equivalent to the 14% improvement observed in Condition 2. Therefore, it could be concluded that performance in conditions 1&2 is comparable and that the slight reduction of errors is only due to the fact that the presence of the matrix at decoding provided a cue that ruled out the possibility of exiting the matrix and hence reduced the likelihood of making wrong guesses.

These results replicate the findings of Experiment (I) which showed that the positive effect of the presence of the matrix is restricted to the encoding stage. Only visual presentation, as opposed to visual recall, brings about a significant reduction in error rate. Such results also support the predictions made in light of the proposed process model and the ALI model. With verbal encoding there is heavy CE involvement to switch attention between external verbal input and internal input (image generation from LTM). Moreover, there is crossing of the 'A-L bridge' to *translate* the verbal statements into a visual image or an 'action representation'. Hence, it was predicted that task difficulty will not be altered as a result of using visual recall.

Subjects' comments in Condition 2 regarding the difficulty of the task and the cognitive processes and strategies used in its processing also appear to be consistent with those of Condition 1. Most subjects (7 out of 8) indicated that the task was very difficult largely due to the difficulty in forming and maintaining a mental image during aural input. The task was described as demanding concentration during listening to the statements. Seven subjects also indicated main reliance on visual imagery. Some of these indicated initial use of verbal memory (i.e. memorising up, left, etc.) but that it did not work. One subject, however, reported using both imagery and verbal memory to perform the task. The image was often described as a pattern (line, question mark, snake, stairs, etc.) rather than a full picture of the matrix. Subjects often reported a tendency to lose this mental "picture" during aural encoding. They also indicated that the task is *"harder as we go on because by then I have different shapes in my mind that confuse me"*. Many subjects also reported that it is easier to image when staring at something or closing eyes. The first few items were mostly reported to be easier to recall because they are rehearsed more during input or as one subject put it *"I didn't take in the last few moves because I was trying to maintain the first ones"* . Typical remarks made by subjects in Condition 2 are shown in Appendix (4.4).

In regard to the new method of visual recall which involved subjects drawing a line representing the path as they saw it in their imagination, the experimenter observed that the response time was very much shorter than under any other previous method of recall. In contrast to the previous form of visual recall which involved placing cards of the digits on a matrix, this new method appears to be more efficient and by far less distracting and subjects appeared to be comfortable with it. In Experiments 1-b&d which involved visual recall by arranging cards, subjects often reported that manipulating the cards disrupted recall.

Condition 3 examined the third possible variation in the modalities of presentation and recall. Unlike Conditions 1&2, the task was presented visually as sequences of 8 displays. The task was, however, recalled verbally by describing the *direction* of the path shown within the matrix. The prediction, based on the process model and the Annett's ALI model, was that performance would be superior to performance in Conditions 1&2. This prediction was based on the assumption that when the task is aurally encoded, there is heavy CE involvement to switch attention between current verbal input and image generation from LTM. Also, within Annett's conception, there is crossing of the A-L Bridge to translate the verbal instructions from the 'language system' into the 'action system'. However, when the task is visually encoded, these redundant encoding processes have presumably been removed and the task materials are encoded directly onto the VSSP.

Results of Condition 3 showed a remarkable reduction in error rate relative to Conditions 1&2. This reduction was significant in comparison to Condition 1 (verbal-verbal) and thus supported the above prediction. However, the reduction in error rate just failed to reach statistical significance in comparison to Condition 2. Some factors may have contributed to this latter result. First, the size of samples tested in these conditions is small. Second, although the task in Condition 2 was presented verbally, it was recalled visually by drawing the image of the path on a real matrix. This new direct method of visual recall may have led to some improvement in performance despite the fact that the task was presented verbally. Also in Condition 3, although the task was presented visually, it was recalled verbally by describing the retained image. This verbal recall is assumed by the ALI model to require crossing of the A-L bridge and also by the process model to require CE involvement to generate verbal output from a visual image. Hence, this method of recall may have made the task in Condition 3 somewhat harder and thus contributed to the nonsignificant difference in comparison to Condition 2. Therefore, it was expected that performance in Condition 4 will show the largest decline in error rate that should be significantly different from both Conditions 1&2. Condition 4 examined the visually presented and recalled version of the 'shortened' variant of the Brooks Matrix which is assumed to be the purest visuo-spatial version in which no redundant verbal and CE processes are involved.

Comments made by some subjects in Condition 3 (see Appendix 4.4) and Conditions 1&2 seem to lend support to the above arguments. For instance, a few subjects in Condition 3 reported occasional use of verbal memory and verbal rehearsal to perform the task. They reported that in a few trials they were verbally rehearsing (subvocalising) the spatial adjectives (up, left, etc.) in addition to maintaining an image. In such cases there was a tendency to encode the task as sequences of words using verbal WM instead of forming an image. This occurred despite the fact that the task was visually presented. A possible reason behind this *verbal recoding* might be the fact that the subject knew that the task will be to verbally describe the path using spatial adjectives. It would be interesting to see whether this verbal recoding will occur in Condition 4 in which no verbal processes and no crossing of the A-L bridge are required. In general, in Condition 3, six subjects indicated that the task was of a medium difficulty whilst one subject rated the task as easy and the last subject rated it as difficult. Five out of the 8 subjects indicated main reliance on visual imagery with some indicating initially using verbal memory and then switching to imagery because using words did not work. The other 3 subjects reported using both visual imagery and verbal memory. They indicated memorising words (e.g. up, left) backed up by an image in case of difficulty or as one subject put it *"you fall back on the picture in case you forget the words"*. In addition, some subjects reported that *converting* the image into words at recall made the task harder. The beginning of the path was often reported to be easier to recall mostly because, as one subject put it, *"I concentrate more on the beginning and then just work out the end"*. The image is often described as a line, a snail, a question mark etc. Subjects reported that they *"black out the relevant squares"* or *"stare at the screen trying to imprint the line in my head and put it upstairs"*. The first trial is reported to be easier because *"you only saw one path"*. Some subjects indicated that they were not always sure of how many items they recalled.

These reports by subjects regarding the strategies used in processing the task appear to be similar to previous comments particularly those of Condition 1 in which recall was also verbal. It appears that whenever recall is verbal there is a tendency by some subjects to, partially, verbally memorise the aurally presented material or to verbally *recode* the visually presented material. In other words, under such circumstances, there is a tendency by some subjects to use the AL in performing the task. It should be noted that Conditions 1&3 involved input-output combinations that required the crossing or recrossing of the A-L bridge. In addition, verbal recall of the 'shortened' variant as in Conditions 1&3 appears to lead to a few subjects occasionally recalling more or less than the 8 items. This occurred whether the task was presented verbally or visually. The reasons behind this are clear. First, unlike visual recall, with verbal recall there is no matrix present at output and thus the subject cannot count the number of squares the path has gone through. Second, unlike the SB task, in this 'shortened' variant no digits are used which provide a cue for the subject to continue recalling until the location of the digit 8 has been recalled or even guessed.

Condition 4 examined the last possible variation in the modalities of encoding and decoding (visual-visual). The prediction, based on the proposed process model and the Annett's ALI model, was that performance of the 'shortened' variant should show the largest drop in error rate which should be significantly different from performance in Conditions 1&2 but not 3. This prediction is based on the assumption that when the task is *aurally* encoded there is heavy CE involvement to switch attention between current verbal input and image generation from LTM. Similarly, within Annett's model (see figure 1.6) when the task is verbally encoded there is crossing of the A-L bridge to translate the verbal instructions from the 'language system' into visual images in the 'action system'. Also, when the task is verbally recalled there is a recrossing of the A-L bridge to translate the visuo-spatial image from the *action system* into the *language system*. It is presumed that such translations require some CE involvement. However, when the task is both visually encoded and decoded, these redundant processes have been removed. The task materials are now, presumably, encoded and decoded directly in and out of the VSSP with no other redundant CE and verbal processes.

Results showed that performance in Condition 4 was, as predicted, significantly superior to performance in Condition 1 (verbal-verbal). This result lends support to the interpretation of the results of Experiment 1-d. In that experiment, the SB task was both presented and recalled visually but, unexpectedly, the results were not significantly different from Experiment 1-a (verbal-verbal). The interpretation was that this result was due to the method of visual recall that was used. In Experiment 1-d subjects recalled the task visually by arranging cards containing numerals on a real matrix. The manipulation and sorting of the cards, which demands hand and eye movements, may have interfered with visuo-spatial imagery and thus led to the insignificant difference. Therefore, it was assumed that using a more direct method of visual recall will bring about a significant difference. Such method involved subjects simply drawing a line on a real matrix representing the path as they see it in their imagination. The results of Condition 4 supported this prediction by showing that performance was superior to its counterpart in Condition 1. The new method of visual recall (by drawing) is more efficient and less distracting than the previous method of visual recall.

Although performance in Condition 4 showed the largest drop in error rate, the t-test just failed to show a significant difference in comparison to Condition 2 (verbal-visual). A similar result was obtained when comparing performance in Conditions 2&3. It was originally predicted that performance in Conditions 3&4, in both of which the task was visually presented, will be significantly superior to performance in Conditions 1&2 in both of which the task was verbally presented. This prediction was based on previous results which showed that visual, as opposed to verbal, encoding of the Brooks task leads to superior recall. Some factors might have contributed to the nonsignificant difference. First, the size of the samples of subjects tested in these conditions is relatively small. Second, although Condition 2 was verbally presented, it was visually recalled by drawing the image. The presence of the matrix at recall was shown to account for the insignificant reduction in error rate seen in Condition 2 in comparison to Condition 1. It was shown that the presence of the matrix at recall led to subjects not making any error as a result of exiting the matrix as occasionally occurs with verbal recall. This slight expected reduction in error rate as a mere result of the presence of the matrix at recall along with the small size of the samples may be responsible for the absence of a significant difference between performance in Condition 2 on the one hand and Conditions 3&4 on the other hand.

Regarding Conditions 3&4, in both of which the task was presented visually, it was predicted that performance should not be significantly different. It has been shown in this study that the positive effects of the presence of the matrix are restricted to its presence at encoding rather than at decoding. That is, provided the task is visually encoded, varying the method of recall in verbal or visual modalities should not result in a significant change in performance. Results confirmed this prediction by showing that performance in both conditions was comparable. Performance in Condition 4 showed the largest drop in error rate confirming the prediction of this condition which examined the purest visuo-spatial form of the task in which no crossing of the A-L bridge is required and which used the new simplified method of visual recall. Regarding the expectation of a low level of performance as a result of combining visual encoding with the new more direct method of visual decoding, the results do not support such an expectation. Performance was comparable to its counterpart in Condition 3 and subjects' reports also indicate that the task is still of a medium difficulty and has not become very easy as a result of this simplified version of the task.

Comments made by subjects in Condition 4 (see Appendix 4.4) appear to support the view that the visually presented and recalled version is the purest visuo-spatial version of the task. None of the subjects reported any occasional use of verbal WM as occurred in Conditions 1,2&3. In Conditions 1&2, which involved verbal presentation, some subjects reported occasional attempts to memorise the statements using rote verbal memory instead of forming a mental image. In Condition 3, which involved visual presentation, some subjects also reported occasional attempts to verbally *recode* the visually presented material instead of forming a mental image probably because they knew they will be recalling the material verbally. Subjects in Condition 4, that involved no verbal encoding or decoding, reported no tendency to verbally recode the task material. Thus, there was no occasional use of the AL component of WM as sometimes occur under other manipulations. The reason behind the disappearance of any use of the *language system* could be that, unlike Conditions 1,2&3, in Condition 4 the material were both encoded and decoded through the *action (visuo-spatial) system*. In addition, subjects in Conditions 1,2&3 tended to complain of a difficulty when translating the verbal statements at input into a visual image or when converting that image into verbal statements at recall. That is, there was difficulty when *generating* a visual image from verbal statements and when *generating* verbal statements from a visual image. In Condition 4, these complaints of difficulties when crossing or recrossing the *A-L bridge* were not reported.

Furthermore, in regard to task difficulty, subjects' reports in Condition 4 appear to be very similar to those of Condition 3 in which the task was also presented visually. The task was mostly reported as being of medium difficulty. It was not described as very difficult or too easy because, as some subjects put it, *"you have to concentrate, it makes you think"* This is in contrast to subjects' reports in Conditions

1&2 in which they indicated that the verbally presented task was very difficult. This is consistent with the process model proposed in chapter 4. With verbal encoding, there is heavy CE involvement to switch attention between incoming verbal statements and image generation. With visual encoding this CE involvement has presumably been minimised since the task is directly encoded with no need to generate images of the matrix from LTM. In other words, the information is assumed to be directly encoded onto the visual buffer (VSSP) with no initial representation in the central processor and subsequent rapid registration of information onto the VSSP as thought (Morris, 1986a) to occur with auditory presentation.

In summary, subjects in Condition 4 reported that the task was easy at the beginning but as the trials progressed it becomes harder because *"by that time you have various images in your mind that confuse you"* Some tests were described as easy and some are quite complex *"the further they go from the starting point, the harder they get"*. All subjects reported relying on visual imagery with the image being described as *"the relevant squares stand out like a shape with no full matrix" or "I traced the path as a line, a shape or a question mark and remembered the deviations from it"* The beginning of the path was reported as being easier to recall because *"I only 'saw' the final x for a second whilst I 'saw' the beginning in my mind at every input"* or *"it is the first thing that happens and you 'see' it more, it is like the alphabetic you know the first letters better"*. These comments regarding the task's difficulty and the strategies used in its processing have some similarities with those made in Conditions 1,2&3. For instance, subjects still describe the image as a shape or a line usually in the form of a snake or stairs and that it makes it easier if this shape is familiar. The beginning of the shape is also indicated as being easier to recall usually because it *'gets rehearsed'* more. However, subjects' reports in this condition differ in regard to the fact that none reported any occasional use of rote verbal memory to perform the task (e.g. subvocally rehearsing sequences of Up, Left, etc.).

Serial position effect:

First, in regard to the comparison of the SP curve obtained on the *shortened* Brooks version to the SP curve obtained on the SB version, the results showed a significant effect of SP. As can be seen in figure 5.3, under both versions of the task the highest error rates were at the last few items indicating the presence of a primary effect and a 'negative' recency effect which is consistent with subjects' reports regarding the processing of the task. Subjects usually report retaining an image that comprises a *shape* or a *line* representing the described path. This image is then used to read off the directions at recall. Subjects indicate a difficulty in recalling the most recent items because the end of the image becomes vague and subsequently gets lost to visual WM. This could explain the almost linear increase of error rate with SP. The ANOVA also showed an interaction between task-version and SP which indicates that the two curves are not parallel. From figure 5.3, the source of this interaction could be positions 5 & 8. Unlike in Condition 1, in the SB condition a high number of errors was made at position 5. In regard to position 8, the highest numbers of errors were made at this position in both conditions. But, unlike the SB condition, in Condition 1 a very much higher error rate occurred at this position. In Condition 1, in which only the directional adjectives were used, the experimenter observed that subjects tended to forget to recall the last adjective or even in a few cases to recall an additional adjective. Some subjects indicated that they finished recall after recalling the seventh position. The use of digits appears thus to provide a cue for the subject as to when to finish recalling. In the SB condition, subjects usually do not stop recalling until they had recalled the location of the digit 8 even if they had to guess. Such a cue is no longer available in this *nondigital* version of the Brooks task.

Regarding the comparison of the SP curve obtained in Condition 2 to its counterpart in Condition 1, the results showed a significant effect of SP. As can be seen in figure 5.4, in both Conditions 1&2, more errors were made at the last few positions indicating the presence of a primacy effect and a 'negative' recency effect.

In both curves more errors were made at the last position which is consistent with subjects' reports regarding the processing of the task as discussed above. The analysis also showed that the SP effects across the two curves are similar. However, for position 8 a higher error rate was made in Condition 1 than in the Condition 2. In Condition 1, subjects sometimes stopped after recalling the seventh statement on the assumption that they have completed the recall process. This is due to the dispensing with the use of the digits which are assumed to provide a cue to the subject not to stop recalling until the location of the digit 8 has been recalled. In Condition 2, visually recalling the task provided the necessary cue by indicating to subjects not to stop drawing until after going through 8 squares on the matrix. The experimenter observed that during visual recall, when in doubt, subjects counted the number of squares through which their drawn line has gone through in order to ensure that all of the 8 'directions' have been recalled.

Regarding the SP analysis for Condition 3, the obtained curve (see figure 5.5) appears to be similar to the curves obtained in Conditions 1&2 in terms of more errors being made at the most recent serial positions. The serial-recall required by the Brooks task appears to be behind the occasional presence of a primacy effect and a 'negative' recency effect. Unlike the current experiments, in free-recall experiments the primary and the most recent items are more likely to be recalled than those in the middle. The obtained SP curve is also consistent with subjects' reports that the end of the line (image) is harder to recall because the beginning is rehearsed more and the end tends to fade during verbal recall. The statistical analysis of the SP data also showed that the curves obtained in Conditions 1&3 are not parallel. From a visual inspection of these two curves, it seems that the source of interaction might be position 8. Unlike Condition 3, in Condition 1 a substantially larger number of errors were made at position 8 than at any other SP.

Regarding the SP analysis for Condition 4, the obtained curve was shown to be different from the SP curves obtained in Conditions 1&2. Unlike these two curves, in this curve (see figure 5.6) the highest error rates were not at the last few positions. Instead, they were at both the first and the last few positions whilst the lowest error rates were in the middle. This pattern is the opposite to the classical SP effect. Another reason for the difference could be the very high error rate at the last position in Conditions 1&2. In these two conditions, which involved verbal presentation, subjects usually reported a difficulty in encoding and recalling the last few moves and indicated that the first few moves were easier to recall because during input they rehearse them more or 'see' them more in their imagination whilst they only 'see' or rehearse the last move once. With verbal recall, subjects also reported a difficulty in retrieving the last few items because during the generation of the verbal statements from the visual image the end of the 'shape' tended to fade. In Condition 4, in which the task was both visually presented and recalled, such difficulties should have been substantially reduced. The SP curve obtained shows a different pattern from the pattern obtained in Conditions 1,2&3 in which error rate increased approximately linearly with SP. These conditions share a common feature which is that they involved a verbal modality at input or output. In Condition 4, although most subjects reported that the beginning of the 'shape' is much easier to recall than its end, the obtained curve showed a different pattern with the highest error rates occurring at both the first and last few positions.

5.2.5. General discussion

As the ANOVA showed, only encoding modality had a significant effect. Changing the method of presentation from verbal into visual led to an improvement in performance of the 'shortened' variant. This result replicates the results of Experiment (I), which varied the modes of input and output of the SB task and showed only a significant effect of input modality. Visual presentation made the SB task very much easier. Thus, the positive effects of the presence of the matrix are restricted to input rather than output. It appears that it is the process of translating verbal instructions into a visual image which demands attentional resources whilst the decoding of the visual image into verbal statements is not much more difficult than drawing a line representing the image. The verbal to visual encoding is the major difficulty presented by the task. Once in store, the retrieval method seems to matter less. This apparent asymmetry of the *A-L bridge* indicates that to generate images from words is an effortful, resource-consuming process whereas attaching words to images involves much less effortful, perhaps even automatic, processes. The asymmetry of the *A-L bridge* so clearly demonstrated in these results can be understood quite simply in terms of Annett's ALI model. The visual buffer, which supports visual and imaginary experience, is part of the representational system. Images can enter directly through the sensory channel but when information comes verbally coded, appropriate images must be generated and this involves the executive or motor system.

This issue of the asymmetrical relationships between verbal and visuo-spatial temporary processing was recently discussed by Holding (1994). Holding pointed out that there are some results in the literature which imply that switching processing resources from a visuo-spatial mode to the AL may be natural and normal whereas switching in the reverse direction might present greater difficulties. Thus, Holding argued that any mutual interference between verbal and visuo-spatial memory tasks will not show symmetrical effects. He predicted that inserting a spatial WM task into the retention interval for a verbal WM task would have effects that are different from the effects of inserting a verbal WM task into the retention interval of a spatial WM task. Results supported this prediction by showing asymmetrical interference: inserting verbal memory into the visuo-spatial delay had little effect on either task but inserting the motor task into the verbal retention interval disrupted both. Holding summarised this effect as showing that one can carry out a verbal task whilst bearing an action in mind, but one cannot carry out an action whilst bearing verbal material in mind.

In general, results of this experiment replicated the results of Experiment (I) which lends support to the view that the 'shortened' variant of the Brooks Matrix is comparable in nature to the standard version and that the use of digits, and thus sentences that instruct subjects to place them in adjacent squares, is redundant. The use of merely spatial directions that describe a path within the matrix is equivalent, in difficulty and processing strategies, to the SB matrix task. The only difference between results of this experiment and results of Experiment (I) was that performance under Condition 4 (visual-visual) was superior to performance under Condition 1 (verbal-verbal). In Experiment (I), performance under Experiment 1-d (visual-visual) failed to reach statistical significance in comparison to Experiment 1-a (verbal-verbal). This change in performance could be attributed to the new method of visual recall by drawing. Unlike the previous method of visual recall (by arranging cards on a matrix), this method appears to be less distracting and a more direct method for revealing the contents of the VSSP.

In conclusion, the version of the Brooks Matrix task examined by Condition 4 (visual-visual) appears to be the purest visuo-spatial form of the task in which no verbal or heavy CE processes are involved. As discussed at the outset of this chapter, such simplified version could be considered as being consistent with Annett's (1982) description of a route 2 experiment in which both input and output are nonverbal 'actions' or information, and which is suggested to be the most appropriate paradigm for studying motor memory, a paradigm that is strictly analogous to the classical verbal memory paradigm. This *simplified* version is therefore assumed to be appropriate for a more specific delineation of the locus of movement interference in WM. The next and final experiment used this simplified version within a movement interference paradigm to examine the effects of various movement tasks during the maintenance stage. It was hoped that this will shed some light on the nature of the VSSP and the role of movement in it, and on the question of whether image maintenance involves a refresh mechanism comprising an 'inner scribe' writing to an 'inner eye' as suggested by Reisberg & Logie (1993).

5.3. Imagery vividness & visuo-spatial memory tasks:

In regard to the correlation of ratings on the VVIQ to performance on the Brooks task, the results showed a nonsignificant correlation. The interpretation of this result is not straightforward. First, the size of the samples of subjects in this experiment is very small. Thus, caution should be taken when considering such a correlation. Second, as discussed in chapter 4, ratings on the VMIQ did not correlate with performance on the Brooks task. The VVIQ was hence suggested as a better alternative to the VMIQ particularly since it has been suggested (Logie, 1989; Logie & Marchetti, 1991) that once the Brooks task has been encoded, the material are retained as a static visual pattern of digits in an imagined matrix. A passive visual store within the VSSP is assumed to be involved in retention of such a static pattern. Therefore, the VVIQ, which consists only of visual items and which is considered (Marks, 1972 & 1973a) to be a specific measure of visual imagery and a valid discriminator of subjects with good and poor visualising ability, was expected to correlate with performance on the Brooks Matrix.

The results, however, showed no significant correlation. This result, along with the previous results which showed no correlation between ratings on the VMIQ and performance on the Brooks task, might be interpreted as suggesting that vividness of imagery is not related to performance or to the ability to use imagery and manipulate images. In other words, vividness of imagery may not be related to performance on 'spatial tests'. The Brooks Matrix task could be considered as a spatial memory test. According to Dean & Morris (1991), there has been a commonly held belief that imagery is involved in a variety of cognitive tasks including spatial tests, and in the resulting research, subjective report measures have played a central role. Research from an individual differences perspective has, however, found very little relation between introspective reports of imagery ability and performance on spatial and other "objective" tests which are believed to require imagery (e.g. Richardson, 1977). Part of the problem may be that individual differences research has been unsystematic, usually ignoring empirical advances in other areas of imagery research. As indicated by Paivio (1988) "the research has consisted mainly of piecemeal attempts to predict memory or some other cognitive skill using scores on a single test that is supposed to measure imagery ability".

Dean & Morris (1991) pointed out that researchers, when studying mental imagery by subjective report, tend to rely on a small set of overvalued questionnaires, the content of which is derived from Galton's original study (Galton, 1883). The content of many of the existing questionnaires seems to have been selected with little empirical or theoretical basis. By examining the existing imagery questionnaires and taking into account the large amount of research into the nature of the imagery system, several weaknesses become apparent. Some studies have indicated that differences in the content of items imagined affect overall measures of imagery ability. Bat-Zion (1986) found that rated vividness decreased the more transformation was required, the more complex a stimulus and the more imaginative an image was. Dean & Morris (1990) found that the VVIQ was not unidimensional, but rather has four underlying factors corresponding to the four groups of items in the questionnaire. Dean & Morris indicate that the fact that differences in the type and content of items affect an overall measure of imagery ability, is of obvious concern when one considers the large difference between items contained in established imagery questionnaires and those in the spatial tests with which rated imagery ability is often compared. The items on established questionnaires such as the VVIQ are all "real world" items and scenes retrieved from LTM of everyday objects or events undergoing a wide variety of transformations and containing varying amounts of information. In contrast, items from spatial tests are frequently abstract, often geometrical, shapes which were perceived then imagined. In other words, they are not previously encountered and placed in STM/the visual buffer, by the processes of perception, where the transformation is often limited to one specific type.

A second concern, Dean & Morris pointed out, is related to the properties of images subjects are required to rate on existing questionnaires. Vividness has been the most popular measure of individual differences since Galton. It is supposed to represent the unique quality of mental imagery, that is, its resemblance to actually perceived stimuli and events. This reliance on vividness as a measure has led numerous researchers to treat imagery as a single ability and to dichotomise performance in terms of "good" and "bad" imagery ability. The findings of Kosslyn and his colleagues (e.g. Kosslyn, 1980, Kosslyn et al, 1990) indicate, however, that imagery involves a number of underlying processing components rather than being a single skill (e.g. vividness). If imagery is used on certain cognitive tasks such as spatial tests, then the study of imagery dimensions which can be linked to underlying functional processes will be of more use in predicting performance on those tasks and in investigating the function of imagery in cognition than will the study of dimensions which bear little or no such relation.

A study was conducted by Dean & Morris in which they attempted constructing an introspective measure of imagery ability based on current theories and findings on the structure of the imagery system and one that could be of practical use in investigating the role of imagery in cognition. The overall conclusion of that study was that there was some support for the idea that imagery is a collection of different abilities, some of which can be measured by introspective ratings, and that the abilities used when solving a spatial task may not be those previously rated on established imagery questionnaires (e.g. VMIQ & VVIQ). The results of that study seem to provide a basis for developing new and more functional introspective measures of imagery that would be effective in studying the role of imagery in cognition.

Dean (1994) in a series of experiments which examined the role of imagery in spatial ability, showed that the VVIQ failed to correlate with performance on some spatial tests such as the Vandenberg mental rotation test and the Comprehensive

Ability Battery-Spatial test (CAB-S). However, subjects' ratings on items of a questionnaire designed by Dean to reflect the three main processes believed to be involved in imaging (formation, regeneration, and transformation) were shown to correlate with spatial tests. These ratings were also intended to reflect the surface proprieties of an image that may be influenced by underlying processes. These ratings were clarity, detail, size, proportion, colour, and vividness. The results of Dean's study did not enable stating in much detail the role of specific imagery processes in performance on spatial tests. Dean was only able to conclude that several aspects of imagery seem to be involved with performance on spatial tests and that the ratings do actually capture unique variance.

Such conclusions do not support the findings of Marks (1973a&b) that ratings on the VVIQ were reliable predictors of accuracy of recall of information and details contained in pictures. Marks presented three STM experiments demonstrating that good imagers (visualisers) correctly recalled more picture details than poor imagers. The task used by Marks required subjects to remember, after a short interval, information contained in pictures that were shown to them on coloured photographs. Marks interpreted his data as suggesting that images have an important function in memory by showing that image vividness facilitates accurate recall. Marks (1989b) stated that the items contained in the VVIQ involve a variety of processes including retrieval of visual images from memory and that, when the VVIQ is used as a predictor of memory performance, it is most appropriate with short delays, where the role of imagination is minimised.

Recently, McKelvie (1994) attempted to tackle this issue of the relationship between the VVIQ scores and memory performance. McKelvie argued that although Marks (1985) paints a uniformly positive picture of the relationship between VVIQ scores and visual memory performance, results are not entirely consistent. With recall tasks and short delays, it has been found that good visualisers were more accurate than poor visualisers (e.g. Marks, 1973a; Housner, 1984; McKelvie & Demers, 1979). However, other studies have shown similar performance levels for the two groups (e.g. MacLeod, 1986; Reisberg et al, 1986; Phillips, 1978; Marks, 1972), and it has even been reported that good visualisers were less accurate (Cohen & Salsona, 1990; Reisberg & Leak, 1987). Moreover, delayed visual recall has been found to be higher for good than poor visualisers (e.g. McKelvie & Demers, 1979).

McKelvie also indicated that although Marks (1977, 1983a) summarises three experiments that demonstrated a positive relationship between imagery vividness and recognition accuracy for pictures of scenes but not words, other studies have had mixed outcomes. For instance, Denis (1987) found a positive relationship for narrative prose; Swann & Miller (1982) found a positive relationship for social information from an interview; and finally MacLeod (1986) found a zero-order relationship for words and for pictures of doodles. Moreover, as with recall, a negative relationship between vividness and accuracy has occurred (e.g. Reisberg et al, 1986; Heuer et al, 1986). However, McKelvie indicated that this set of varied results does not necessarily invalidate the VVIQ, since construct validity is multifaceted (McKelvie, 1990) and imagery vividness is not expected to predict visual memory in all circumstances (Marks, 1989b). For instance, some of the results showing no difference, occurred under instructions to form images which may minimise natural processing differences (Marks, 1972). In this context, the Brooks task is a task that instructs subjects to form images. Furthermore, the conflicting recall results, McKelvie argues, may reflect differences among different kinds of task (recall of picture detail, paired-associated recall, free recall). With its images of varied scenes, the VVIQ may be more suitable for predicting memory for complex meaningful material.

A factor which may encourage a positive VVIQ/memory performance relationship, McKelvie argues, is the use of a holistic strategy in which subjects simultaneously process configural properties of the stimulus. Such opportunities are thought to be available with complex meaningful pictures on which Marks (1973a, 1977, 1983b) reported better recall and recognition memory performance by good than by poor imagers. In fact it has been reported (Gur & Hilgard, 1975) that good imagers were not only faster than poor imagers at pointing to a difference between two successively-presented pictures, but also were more likely to indicate seeing the difference 'pop out'. Poor imagers, on the other hand, preferred recalling individual picture details one at a time, then search for them. Berger & Gaunitz (1979) indicated that good imagers were faster than poor imagers if the holistic (or imagery) strategy was used. In addition Wallace (1991) has argued that superior visual search and proof-reading performance by good over poor imagers can be attributed to holistic processing.

Hence, McKelvie argues, if vivid imagers are more likely to use and profit from holistic processing than poor imagers, their memory accuracy should be worse than that of poor imagers when they cannot engage in this strategy. However, when both configurational and detail processing can occur, group performance should not differ. This would be consistent with the hypothesis that the VVIQ predicts memory for complex meaningful but not meaningless material. Furthermore, it has also been argued (e.g. Richardson, 1988) that the self-report scale of the VVIQ, along with other measures of subjective vividness, is inherently flawed since there is no objective standard of vividness by which different subjects can impute the same meaning to the 5 scale points. Such a remark implies that subjects may answer honestly but that their scores are not comparable, or that they may respond on some basis other than perceived vividness. Although Marks (1977) found no significant relationship between VVIQ scores and the response criterion beta, indicating that good visualisers do not simply adopt a more lenient criterion than poor visualisers, it has been suggested (Cohen & Salsona, 1990) that VVIQ ratings may reflect general self-confidence or even overconfidence especially if the respondent has just completed a criterion task. Such a possibility is supported by the finding (Reisberg et al, 1986; Reisberg & Leak, 1987) that a negative relationship between vividness and memory performance was accompanied by a positive relationship between vividness and confidence.

In attempting to examine these hypotheses and issues, McKelvie used facial photographs which are claimed to possess both component (detail) and configural (holistic) properties, at least when shown upright. McKelvie's study evaluated the competing holistic and rating scale proposals by comparing accuracy, confidence, and response speed for immediate recognition memory of upright and inverted faces. If good visualisers are more likely than poor visualisers to engage in holistic processing then their recognition memory performance for inverted faces will deteriorate more than that of poor visualisers. The results showed that inversion seriously disrupted recognition memory accuracy but the holistic hypothesis was not supported. The effect of inversion did not significantly differ for good and poor visualisers for either accuracy or latency. Also the VVIQ scores were related to confidence in both upright and inverted conditions, with good visualisers reporting greater confidence in their performance than poor visualisers. Some subjects appear to have responded to the VVIQ on the basis of confidence rather than on an honest assessment of vividness. Such results are also consistent with a significant positive correlation (e.g. Richardson, 1979) between scores on the VVIQ and reported social desirability on the Personal Reaction Inventory. McKelvie argues that, taken together, these indications suggest that VVIQ ratings may reflect an instrument factor. McKelvie's study also indicates that some people take greater care to answer honestly the VVIQ than others and that the VVIQ seems to be easily contaminated by the effect of context. That is, subjects seem to be cued to rate their visual imagery as less vivid when they had just experienced a more difficult task. McKelvie pointed out that although Marks (1989a) noted that some influence of context on the VVIQ is to be expected, such results should alert researchers to the cueing effects of a criterion task on the VVIQ. In short, the McKelvie's results confirmed previous reports of no relationship between the VVIQ and recognition memory for faces and offered no support for the holistic processing hypothesis.

McKelvie concluded that since the results suggest that VVIQ ratings are affected by an instrument factor, they cast doubt on the VVIQ as a measure of visual imagery vividness.

The findings of this, and the previous, experiment regarding the VVIQ and VMIQ not correlating with performance on the Brooks, also support some other conclusions and indications in the literature. For instance, Neisser (1970) concluded from data obtained by Sheehan & Neisser (1969) that verbal reports of image vividness are of little predictive value. Baddeley & Logie (1992) indicated that there is abundant evidence from studies of visual imagery to suggest that rated vividness does not predict the capacity of subjects to store and manipulate visuo-spatial information. Craig Hall (personal communication) pointed out that such results of no correlation are expected with random sampling. With random sampling the majority of subjects tend to fall in the middle in terms of imagery vividness. However, a correlation may occur, Hall argues, if subjects are preselected as low and high imagers.

However, these findings do not support some positive results in the memory literature such as the finding (Marks, 1973a; Rossi & Fingeret, 1977) that good visualisers performed better on picture and paired-associate recall, respectively, under conditions that included controls for verbal processing. In this study, there has so far been no support for such positive findings. Results have shown no significant correlation between VVIQ or VMIQ ratings and performance on the Brooks task. It should be noted, however, that unlike the Brooks Matrix task, the memory task used by Marks was not mainly spatial, but rather a visual recognition task. Also, before a conclusion on the relationship between these subjective tests of imagery vividness and performance on the Brooks task is made, a much larger sample of subjects needs to be tested.

Chapter 6

Maintenance of visuo-spatial information

Experiment IV: The effects of various movement tasks on maintenance of the 'simplified' variant of the Brooks Matrix task.

6.1. Introduction:

Experiment III examined the 'shortened' variant of the Brooks Matrix task. In this variant, the digits were dispensed with and thus the pattern TBR was either presented verbally as merely a series of directional adjectives, or visually as a series of displays with each display showing only one X at a time that indicates the direction of a path within the matrix. Also, in that variant a more direct method of visual recall was examined which involved simply drawing a line on a matrix representing the mental image of the path. The overall results showed that the task has not been significantly altered by dispensing with the use of numerals which was assumed to be redundant. Subjects' reports regarding the difficulty and the processing strategies of the various input-output combinations of the task supported the findings from recall data. The results also showed that the new method of visual recall was much more efficient than the previously used method of visual recall which involved arranging cards containing the digits on a real matrix. Recall by drawing the image appears to be a more direct way of revealing the contents of the VSSP with minimum contamination by other factors. Hence, the validity of the 'shortened' variant appears to have been established and thus it could be used to examine some hypotheses regarding the effects of various movement tasks on retention of visuo-spatial information.

As has been indicated, this 'shortened' variant was examined by varying the encoding and decoding methods between verbal and visual modalities which resulted in four different input-output combinations: verbal-verbal, verbal-visual , visual-verbal, and visual-visual.

The first combination (verbal-verbal) is identical to the SB task in terms of its processing requirements. In addition to its visuo-spatial elements, it is also supposed to have verbal as well as CE components. Within the proposed process model, there is a heavy CE involvement at encoding to switch attention between external verbal input and internal input which is image generation from LTM. Within the ALI model (Annett, 1982), there is a *crossing* of the *A-L bridge* at encoding to ***generate*** a visual image from the verbal statements, and there is also a *recrossing* of the *A-L bridge* at decoding to ***generate*** the verbal statements from the retained visual image. These redundant processes make the task complicated and probably obscure our understanding of the VSSP since the CE is suspected to be heavily involved during these two *generating* processes. It also follows that the encoding and decoding processes, being demonstrably cross-modal, may be contributing more to the experimental results than the maintenance process which is central to the study of a refresh mechanism in the VSSP.

In contrast, the fourth input-output combination (visual-visual) is presumed to be the purest visuo-spatial form in which no verbal or heavy CE processes are involved. Instead, the task is now directly coded and decoded. Within the proposed process model, the task now is encoded directly onto the visual buffer with no need for heavy CE involvement to switch attention between two sources of input as occurs with verbal presentation. There is no longer any need to generate a visual image of the matrix since the task is visually presented. In terms of the ALI model, there is no longer any crossing or recrossing of the *A-L bridge* since the information is now directly encoded onto the 'action representation' element of the 'action system' and directly decoded through the 'action production' element of that system. Thus, there is no involvement of the 'language system' since the task now has no verbal component and the AL should not be involved in the processing of this 'purified' visuo-spatial version.

The need for such a simplified visuo-spatial version is highlighted by some criticisms of previous studies of the VSSP. For instance, Morris (1986a) indicated that a major problem with the early Baddeley experiments was that all tasks used, including the Brooks Matrix, have a large verbal component. The spatial tasks used require initial verbal encoding with transformation into spatial representations. This implies that the stimuli must first be represented in the central processor with subsequent rapid registration onto the VSSP. More recently, Wang & Bellugi (1994) indicated that a variety of tasks has been employed for the assessment of the VSSP. Many of these tasks, including of course the Brooks Matrix, incorporate the confounding task of constructing a mental image from verbal input. Such criticisms should not apparently apply to the simplified visually presented and recalled version of the Brooks Matrix.

With this simplified version of the 'shortened' variant, it would be possible to shed more light on the central question addressed in this project of whether interference by concurrent movement is due to the sharing of a central WM resource, the CE, or to the sharing of a visuo-spatial WM resource that involves a refresh mechanism comprising an *inner scribe* writing to an *inner eye* as proposed by Reisberg & Logie (1993). Concurrent movement has been found to interfere with information believed to be held in the VSSP with interference mostly shown during encoding and retrieval rather than during image maintenance (e.g. Baddeley & Lieberman, 1980; Morris, 1987; Quinn, 1991). However, it is not clear why movement should be so disruptive. Is it because a common WM resource is required? If so, is this resource a representation of space or is it perhaps the involvement of the hypothetical CE? With the current variant which facilitates visual encoding, it might be possible to shed some light on the issue of whether movement interferes with the VSSP as such, not just by adding to the load on the CE during encoding. Results of Experiment II, appear to suggest that active encoding of visuo-spatial information, even when the information is visually encoded, does require a considerable CE involvement. Unlike encoding, maintenance of visuo-spatial information is assumed to rely mainly on a specialised visuo-spatial resource and loads the CE less, at least when the maintenance interval is short.

Within the WM literature, there is an increasing number of studies on visuo-spatial storage and processing as studied during encoding and retrieval of information (for a review see chapter 2, Baddeley, 1986; Logie, 1991, 1995). However, maintenance of information in the VSSP has not been widely studied. Smyth & Scholey (1994a) pointed out that in comparison to verbal information, less is known about the ways in which visuo-spatial information is maintained over short periods of time, although there is evidence that such information is not maintained by verbal recoding (Allen, Marcell, & Anderson, 1978). Baddeley (1986, 1990) has suggested that visuo-spatial and verbal material may be held in two separate, passive, perceptual stores with rapid decay in each store prevented by an active control process based on a response system. Baddeley comments that, "both systems appear to have taken advantage of an essentially passive perceptual input store. In both cases, the problem of coping with rapid decay from the store appears to have been solved by an active control process based on a response system, articulation in the case of the AL and eye movement in the case of the VSSP" (1986, p.120). According to Baddeley, these operations allow the transformation of a passive perceptual store into an active memory system which enables the individual to take information out of the relevant input store and to feed it back and hence continuously refreshing the trace and minimising forgetting. However, Baddeley indicated that although the analogy between the model of the AL and the VSSP is attractive, the evidence for the refreshment of a visual trace by implicit motoric activity is still relatively weak. Recently, Baddeley (1992a) argued that it is still not clear what process underlies the active rehearsal of visual imagery, playing the spatial equivalent to the role of subvocalisation in the AL. Thus, the extent to which eye movements are implicated in such active rehearsal of material in the VSSP is questionable and Baddeley himself admitted that other types of rehearsal mechanism are conceivable and may indeed be more plausible (Baddeley, 1986).

In general, according to Baddeley's view, maintenance rehearsal refreshes a trace in WM that decays over time. If the rate of rehearsal for the complete sequence is less than the rate of decay for any item, then a sequence can be maintained. With verbal material, this view has been supported by various findings that indicate that the length of time it takes to speak words affects the number of items that can be held in WM. The length of the words TBR affects memory span and so does the rate at which subjects can articulate (e.g. Baddeley et al, 1975a). In regard to the visuo-spatial store, Baddeley (1986) suggested that maintenance of visuo-spatial material is based on implicit motor activity, although he also put forward an alternative view indicating that covert visual attention is also involved in such maintenance. Having argued that the rehearsal of verbal material is based on taking information out of a phonological store and feeding it back by a process similar to articulation, Baddeley argued that rehearsal of visuo-spatial material is based on taking information out of a passive visual perceptual store and feeding it back by a process similar to eye movements. Evidence from a range of studies using dual-task methodologies supports this view but does not test it directly (e.g. Baddeley & Lieberman, 1980; Idzikowski et al, 1983; Farmer et al, 1986; Quinn & Ralston, 1986; Smyth & Pendleton, 1989). These studies have demonstrated that eye or hand movement to spatial targets does interfere with other spatial tasks if the two tasks are concurrent at the encoding stage. As these movements were directed to targets in space, they presumably involved the use of internal spatial representations in the planning and control of the action. These findings appear to be consistent with the view that visuo-spatial WM is maintained by a system that uses motor processes shared by actual movements and that the eye and hand movements used as secondary tasks may prevent the maintenance system from operating (Smyth & Scholey, 1994a). However, it has been indicated (e.g. Logie & Baddeley, 1990) that such secondary tasks also carry a memory load and have a sequence component, and they may interfere with spatial memory at encoding because general-purpose resources are involved rather than a purely spatial system. Therefore, dual task paradigms (concurrent tasks at encoding) may not be the most appropriate approach in the visuo-spatial domain.

An alternative approach is to use interference during a retention interval to investigate maintenance. Researchers who have done this have used various primary and secondary tasks and have produced inconsistent evidence of interference as was thoroughly explained in chapter 2 when discussing the encoding vs maintenance issue. In short, within the WM framework, there are only a few studies that have examined the effects of movement interference during both encoding and maintenance of information in the VSSP (Idzikowski et al, 1983; Morris, 1987; & Quinn, 1988a, 1991). Results of these studies have mostly isolated the active encoding stage as the locus of the interference. However, other studies using different paradigms, have examined interference during the maintenance stage only and reported movement interference with maintenance of visuo-spatial information (Logie & Marchetti, 1991; Smyth & Pendleton, 1990; Smyth & Pelky, 1992; Smyth & Scholey, 1994a). However, the findings by Smyth & Scholey imply that the source of interference lies in the over-writing of a representation of space rather than in the generation of voluntary movement (see chapter 2 for details).

With these contradictory and controversial results regarding movement interference with maintenance of visuo-spatial information and regarding the ways and mechanisms by which this information is maintained over short periods of time (see chapter 2 for details), it is clear that this issue of interference during maintenance needs further clarification. Recently, Logie (1995) indicated that much of the work on the VSSP has been concerned with visuo-spatial storage and processing as studied during encoding and recall of visuo-spatial information and there is very little literature addressing the means by which information is maintained in visuo-spatial memory tasks. Similarly, Baddeley (1992b) pointed out that there is little evidence as to the nature of the refresh mechanism in the VSSP.

Hence, it is the purpose of this experiment, using the 'simplified' version of the Brooks Matrix task, to attempt to shed some light on this issue and, in particular, on the issue of whether the VSSP involves a refresh mechanism comprising an 'inner scribe' writing to an 'inner eye' as proposed by Reisberg & Logie (1993) and explained in chapter 2 when discussing the visual vs spatial debate. In general, the WM model (Baddeley & Hitch, 1974; Baddeley, 1986) postulates two sub-systems, one verbal and one visuo-spatial. As in the ALI model (Annett, 1982), each subsystem comprises a receptive and an executive (motoric) component. The receptive component comprises a sensory buffer in which material is held in a temporary store and in a quasi-sensory form. The sensory buffer holds material for short periods, and not only can new material replace the old, but the undisrupted trace decays rapidly unless refreshed. Hence, each subsystem is assumed to comprise a sensory buffer that constitutes current conscious experience and which is maintained by a read-write loop. In regard to verbal WM, verbal material is maintained in conscious awareness and available for retrieval by means of an articulatory loop. In this loop, the material is spoken subvocally *(inner voice)* and so re-enters the sensory buffer *(inner ear)*. This model of verbal WM has been extensively researched and empirically supported (see chapter 1 & Baddeley, 1986 for a review) and the most convincing evidence comes from experiments demonstrating the effects of articulatory suppression. The specialised verbal WM resource can only be used for one task at a time such that another verbal task, even simply repeating "the, the, the" will interfere with the subvocal repetition (maintenance) of the TBR verbal material. In short, it is argued that verbal WM comprises an *inner ear* (short-term acoustic store) which is maintained by an *inner voice* involving some elements of the normal speech production mechanisms.

Annett (1995) indicated that the major question then is whether visual WM, the VSSP, can be regarded as an *inner eye* and whether information in this short-term visual store or buffer can be maintained by an *inner scribe* which effectively reads the material from and then rewrites the material to the buffer. This is the proposal put forward by Reisberg & Logie (1993) and which clearly implicates motor production processes in the retention of visuo-spatial material in WM. However, as indicated by Annett, an apparent problem with this proposal is that whilst the *inner voice* may generate inputs that are very similar to the original stimulus, the *inner scribe* may not be able to generate all the features of the original material using a single motor resource since painting pictures is a process that is different from the process of repeating words.

In general, Reisberg & Logie (1993) proposed a refresh mechanism in the VSSP which parallels that of the AL. They indicated that for verbal WM and auditory imagery, there is a partnership between the 'passive phonological input store' (inner ear) and the 'active articulatory rehearsal process' (inner voice). Verbal material can be maintained if the *inner voice* continuously repeats the current contents of the sensory buffer to the *inner ear*. As indicated above, there is strong empirical support for the AL, and for auditory imagery, due to this conception or partnership. Reisberg & Logie (1993) and Logie (1993) argued that a similar partnership between sensory and motoric elements exists for the VSSP and visual imagery. They proposed that the VSSP could be divided into two stores, one visual and the other spatial or motoric. The visual element or buffer (the passive visual store) is called the *inner eye* which holds static visual representations and is linked to the visual perceptual system. The spatial-motoric element (the active visual rehearsal process) is called the *inner scribe* which can rehearse a sequence of movements and is linked with the mechanism of motor planning. The *inner scribe* can feed or write information into the *inner eye* (visual buffer) in order to prevent decay or to allow manipulation and transformation of visual images. The mechanism for the *inner scribe* is not as clear as that of the *inner voice* (subvocalisation) but it presumably involves the generation of visual images. This partnership was indicated by Reisberg & Logie as being plausible but still speculative and it was proposed to be an important focus for future research.

Thus, Reisberg & Logie suggested an *inner scribe* which re-writes material to the *inner eye* in almost the same way that the *inner voice* recirculates (articulates) material to the *inner ear* , and they go so far as suggesting that this particular species of visuo-spatial imagery could in fact be motoric. They indicated that visual imagery has two species, one purely visual and the other is motoric. For motoric imagery, one images by planning or mapping out a series of possible movements with little or no involvement from the *inner eye*. This motoric element can produce a covert stimulus which then 'feeds into' the *inner eye*. They also indicated that some cases of 'visual imagery' may in fact rely on planning mechanisms within the motor system. Annett (1995) pointed out that, when closely examined, this proposed analogy between verbal and visual STM, appears to have only rather indirect support and some serious theoretical difficulties.

The first of which, Annett argues, is that phonological coding is time-dependent whereas visuo-spatial coding is not and anyone who has used the stop frame facility on a VCR will readily appreciate such a point. Visual identity and spatial location can be preserved as long as the image is not overwritten and the storage medium does not degrade whereas acoustic information can only be available for retrieval by replaying the tape. In other words, speech is time-dependent, it can only be heard when running in real time, as on an audiotape. Visual patterns however are not as in, for instance, having a "frozen" frame on a video. Consequently, the AL is a necessity for phonological coding whilst a parallel visuo-motor loop may not be for retention of visuo-spatial material. Another difficulty with the proposed analogy, Annett indicates, lies in the nature of the perceptuo-motor coupling of phonological and spatial information. Speech, on the one hand, is close-coupled in that speech production is largely dependent on intact auditory feedback, and also self-generated speech closely resembles other-generated speech to the extent that it has been suggested that auditory hallucinations may be due to a failure to distinguish self- from other-generated stimuli. Coupling between spatial perception and movement, on the other hand, does not seem so close unless one fully accepts the Hebbian hypothesis that eye movement is fundamental to shape recognition. For instance, Annett indicates, perceptually identical circles and triangles can be produced by an almost infinitely varied combinations of motor activity, the motor constancy phenomenon, whilst production of recognisable speech is much more highly constrained.

Despite these difficulties, the proposed analogy between mechanisms of the VSSP and the AL might be true for the observation (Annett, 1982) that the echoic and imitative nature of speech perception and production may well have a parallel in the ability to imitate bodily and facial gestures. In this regard, Annett suggests that, at the end, the VSSP might turn out to comprise not only one or two but at least three components. The first of which is related to retaining features such as colour and shape which *identify* objects and are not time-dependent, whereas the second is related to retaining *spatial* information (both relative and absolute) that could be, for instance, used to approach or avoid the object. A third component may be specific to the encoding of action information, especially information that are needed to interpret and to imitate the perceived actions of others. As indicated in chapter 2, the possible existence of such an imitation-specialised motor component in WM was similarly suggested by Smyth & Pendleton (1989). Annett indicates that since it is only this third component which requires the encoding of time-dependent information, it is only in this regard that an action-perception feedback loop (a refresh mechanism) would be advantageous to maintaining information in WM.

In regard to the relationship between the *inner eye* and the *inner scribe* on the one hand and the CE on the other, Logie (1993) indicated that it is possible that some form of attentional resource is required in some of the operations attributed to these two subcomponents. In terms of the ALI model (Annett, 1982, see chapter 1), the 'action system' comprises two elements: a sensory element called 'action representation', and is assumed here to correspond to the *inner eye*, and a motoric element called 'action production' and is assumed here to, more or less, correspond to the *inner scribe*. Annett (personal communication) indicated that a possible role for the CE is in the activation of the motor elements. Thus, when sensory input leads to motor output or when motor activation leads to sensory activation or imagery, the CE is involved. Hence, the CE, Annett argues, is in effect the mechanism which controls the level of inhibition/excitation of the motor output (executive) system. In addition, in the account of mental imagery put forward by Kosslyn et al (1990) and elaborated by Kosslyn (1991), image maintenance can be considered as a special case of image generation, with the generation mechanisms simply being used repeatedly to refresh an existing pattern of activation in the visual buffer. According to Kosslyn (1991) images fade quickly and require effort to maintain and the more perceptual units that are included in an image, the more difficult it is to maintain. Therefore, it is the presumption in this experiment that the operation of the *inner scribe* does involve CE and motor resources.

In general, it is assumed that critical evidence for the existence and nature of the proposed refresh mechanism should come from interference effects of secondary tasks presented during a retention interval rather than during the encoding stage. Carrying out two concurrent tasks at the encoding stage presumably involves general purpose resources and may confound our understanding of this proposed mechanism. As explained in chapter 2, few studies have examined interference during maintenance with the results being inconsistent. For instance, Morris (1987) and Quinn (1988a &1991) showed that spatial movement did not interfere with maintenance of visuo-spatial information (the Brooks Matrix in Quinn's studies) whereas the same movement task disrupted the encoding of visuo-spatial information. These results would imply that spatial movement does not disrupt the 'refresh' mechanism of the VSSP in the same way that verbal secondary tasks seem to disrupt the refresh mechanism, the AL, in verbal WM. In contrast, other studies using different paradigms have shown that spatial movement performed during maintenance interfered with the recall of visuo-spatial items with interference being attributed to various factors such as the sharing of a rehearsal mechanism that is also involved in the control of movement (e.g. Logie & Marchetti, 1991) or simply the sharing of spatial attention (e.g. Smyth & Scholey, 1994a).

The aim of this experiment was then to examine the effects of various secondary movement tasks on the maintenance phase of the 'simplified' visually presented and recalled version of the Brooks Matrix task. The overall objective was to attempt to shed some light on the question of whether image maintenance involves a refresh mechanism (a rehearsal loop) comprising an *inner scribe* writing or feeding information to an *inner eye* as proposed by Reisberg & Logie (1993).

The previous experiments in this project have shown that manipulating the encoding modality of the Brooks task from verbal into visual brings about a significant change in performance whereas manipulating the decoding modality makes no difference. Once the information had been encoded, the retrieval method seems to matter less. This asymmetry of the *A-L bridge* can be understood in terms of the ALI model. The visual buffer, which supports visual and imaginary experience, is part of the representational system. Images can enter directly through the sensory channel but when, as in the SB task, information comes verbally coded, appropriate images must be generated and this involves the executive and the motor system. The *inner scribe* is presumably necessary for the formation of images. The above question of whether a refresh mechanism, involving the *inner scribe*, maintains material in the VSSP remains open and it will not be easy to demonstrate using the SB matrix task. Performance on this task is dominated by the image generation process which places heavy demands on CE or motor resources. Also, it appears that such a mechanism will not be easy to establish at the encoding stage since it seems that encoding, even visual encoding, loads the CE. Hence, performing a secondary task whilst at the same time encoding a primary task will most likely involve general purpose resources in addition to specialised mechanisms. However, such a demonstration is assumed to be possible using the 'simplified' visually presented and recalled version of the Brooks Matrix from which the verbal and heavy CE components have been removed. It would be possible to examine whether secondary movement interferes with maintenance of visuo-spatial information with minimum contamination by the CE especially since it appears that encoding loads the CE more than maintenance, at least when the maintenance period is short.

In regard to the length of the maintenance period, it is suggested that the longer the maintenance period the more prone the retained material to decay and hence the more the need to operate the refresh mechanism (loop). Hence, a long maintenance period should be used when examining the question of whether material in the VSSP is maintained by a refresh mechanism comprising an *inner scribe* feeding information to an *inner eye.* Within the WM literature, studies that examined maintenance of visuo-spatial material have used various lengths of the maintenance period. For instance, Morris (1987) used various lengths of the maintenance period (5, 10, 20 seconds) and presentation time of the TBR material was 10 seconds. Quinn (1988a) used a maintenance period of 20 seconds which was equivalent to the presentation time of the TBR material (the Brooks task). Quinn (1991) used a maintenance period of 18 seconds which was half of the presentation time of the TBR material (a modified version of the Brooks Matrix). Logie & Marchetti (1991) used a retention interval of 10 seconds and the presentation time of the TBR material was 6 seconds. Smyth & Pelky (1992) used retention intervals of 5 and 15 seconds, and Smyth & Scholey (1994a) used a retention interval of 12.5 seconds. In the current experiment, which examined whether the VSSP has a rehearsal loop comprising an *inner scribe* writing to an *inner eye*, a longer maintenance period of 30 seconds was used. This was assumed to be long enough for the hypothetical *rehearsal loop* to be needed to refresh the retained material. This maintenance period was longer than the presentation time of the primary Brooks task which was presented as sequences of 8 displays with each display being presented at the rate of 2.5 seconds making the total presentation time 20 seconds.

The primary visuo-spatial task used in this experiment was the 'simplified' variant of the Brooks Matrix which was examined by Condition 4 in Experiment III. This spatial matrix task in its standard form is assumed to involve maintaining an array, locations within it, and the order in which the locations are presented (Smyth & Scholey, 1994a). Three movement tasks were used to examine their interference effects on maintenance of the primary task. These tasks were: simple tapping, regular spatial tapping, and random spatial tapping. **Simple tapping** and **regular spatial tapping** were used in Experiment II and, as discussed there, they have been widely used in the literature and their memory and processing demands are relatively well known.

The **random spatial tapping** task was the same as the spatial tapping task in terms of having the same spatial component but it differed in regard to one important element which is the rate of tapping. Instead of tapping at a regular rate with fixed inter-stimulus intervals (1 tap per second), subjects here tapped round 4 targets in response to a variable auditory signal. The inter-signal intervals were *randomly* generated by a computer with a minimum interval of 0.5 second and a maximum interval of 1.5 second. This random rate of tapping is assumed to load the CE since it requires concentration to anticipate the signal and decision making regarding when to tap and when to pause whereas the regular signal is repetitive and thus should not impose a load on the CE.

This random spatial tapping task has not been used in the published literature as a task that loads the CE in addition to its spatial component. However, a slightly similar task, random generation, has been used as a possible indicator of CE functioning, or of allocation of attention (e.g. Baddeley, 1966c, 1986; Evans, 1978; Hayes & Broadbent, 1988; Logie & Salway, 1990; Wagenaar, 1972). Random generation involves requiring subjects to generate at random items from a well known and well defined set such as the alphabet or the numbers 1-10. It has been shown to involve executive-like cognitive resources in that subjects have to keep track of the frequency with which they generate each item, and inhibit well learned sequences such as 'a-b-c' from occurring. It has also been shown to interfere with tasks associated with executive processing such as card sorting (Baddeley, 1966c). Baddeley (1966c, 1986) argues that random generation requires execution of strategies, as should reflect the operation of a CE, although its characteristics as a secondary task are relatively unexplored. Recently, Baddeley (1993) and Logie (1995) cited the use of a task which is more similar in its processing demands to the random spatial tapping task used in this experiment. This task, random key pressing, involved giving subjects a specially constructed keyboard with 10 keys, and asking them to press the keys one at a time in as random a fashion as possible. This random key tapping task was intended to act as a non-verbal equivalent to oral random generation for loading the CE. Baddeley argued that randomly pressing keys may provide a suitable nonverbal analogue of alphabetic generation and that the possibility of utilising random generation in more than one modality should substantially increase the potential value of the technique.

It was hypothesised that a regular spatial tapping task, that has been used as a spatial suppression task (e.g. Farmer et al, 1986; Smyth et al, 1988) will interfere with maintenance of the current variant of the Brooks Matrix. The visuo-spatial information (mental representation of the path) is assumed to be maintained in a visuo-spatial WM store, and the spatial 'suppression' task is assumed to occupy the same resource and thus should overwrite the contents of that store. This prediction is based on the assumption that the VSSP is similar to a sketchpad or a board on which visuo-spatial information is registered. Making spatial movements, such as repeatedly tapping 4 targets in space, should over-write the representation registered on the sketchpad. Also from the properties of the ALI model (chapter 1), it can be predicted that retention of visual information that does not evoke action will not be disrupted by concurrent spatial (motor) activity but that visual information about *spatial location* will be disrupted since it activates the motoric element. In addition, since the maintenance period was relatively long in this experiment, interference should occur because the retained visuo-spatial material would be more prone to decay and the hypothetical refresh mechanism would be prevented from operating by spatial tapping. If the *inner scribe* is involved in the control and planning of movement, as proposed by Logie (1989, 1995; Reisberg & Logie, 1993), then the requirement to generate a series of irrelevant spatial tapping movements during image maintenance will disrupt this refresh mechanism leading to poorer recall of the original visuo-spatial information. Maintenance of the original material, at least during a longer retention interval, is assumed to be accomplished by the refresh mechanism. If visuo-spatial or spatial information is primarily maintained in an array format that is similar to that formed with a mental image, then rehearsal in spatial STM tasks and maintenance of an image may be related. If this array is scanned to refresh it, there is no reason why this should not be in spatial terms (Smyth & Scholey, 1994b).

Furthermore, if the VSSP has a rehearsal loop involving an *inner scribe*, which refreshes the contents of the sketchpad (inner eye), then adding a CE component, unpredictability, to the above spatial suppression task should show further interference. Tapping round 4 spatially distributed targets in response to a random, as opposed to a regular, auditory signal is assumed to require attention, concentration, and vigilance in order to tap in time to the unpredictable signal. These general purpose processes such as concentration and judgement making should load the CE which is assumed by the WM model to be responsible for such functions (see chapter 1). The *inner scribe* is presumed to involve CE as well as motor processes. In other words, the suggested refresh mechanism, comprising an *inner scribe* feeding information into an *inner eye*, is an active rehearsal loop that should also involve CE processes. Hence, tapping 4 spatial targets in response to a random signal should lead to greater interference because of its assumed additional executive loading. In a long maintenance period, it is assumed that the VSSP will need to be 'refreshed' by the *inner scribe* which is taken to involve the CE. The longer the maintenance period, the more susceptible the mental representation to decay and thus the more the need to operate the rehearsal loop to rewrite the information and refresh the content of the VSSP.

Thus, it was hypothesised that if maintenance of visuo-spatial information involves only a passive visuo-spatial store (a passive screen onto which visuo-spatial material is painted), then a regular spatial suppression task should over-write the information whilst a random spatial tapping task, that loads both the VSSP and the CE, should not lead to further interference. On the other hand, if image maintenance is via a covert motor response that involves a refresh mechanism comprising an *inner scribe* writing information to an *inner eye*, then the regular spatial tapping task, that loads the VSSP, should interfere whilst the random spatial tapping task, that loads both the VSSP and the CE, should lead to further interference due to its assumed additional executive loading. This further interference should occur because the *inner scribe* is assumed to be an active rehearsal process that involves general purpose resources for its operation.

Finally, it was hypothesised that a simple tapping task, involving repeated tapping with the stylus of the same target and hence having no spatial or CE components, will not interfere with maintenance of visuo-spatial material. This task is being used as a control task which should not make specific demands on spatial or CE resources, but nevertheless provides some load (Quinn & Ralston, 1986; Smyth & Pelky, 1992). Logie & Salway (1990) indicated that this task constitutes a secondary task to investigate the effects of response production at a preset rate and it could be used to gauge whether any disruptive effects of the spatial suppression task could be merely attributed to a requirement to generate a repeated motor response.

6.2. Method

A) Material & equipment

The primary visuo-spatial task was the 'simplified' visually presented and recalled variant of the Brooks Matrix task which was examined by Experiment III, condition 4. Three movement tasks were used to examine their interference effects on maintenance of this memory task. These were: simple tapping, regular spatial tapping, and random spatial tapping. The following are descriptions of the tasks:

The primary task:

The primary task was the 'purified' variant of the Brooks Matrix which was examined by condition 4 in Experiment III. In that condition, the task was presented visually as sequences of 8 displays on a computer screen using the application HC. Each display showed the matrix with only one cross in the centre of the successively designated square through which the path is moving. The same material and equipment used to present the task visually in Conditions 3&4 of Experiment III were used to present the task in this experiment.

The task was also recalled visually by drawing a line on a real matrix representing the mental image of the path (see Appendix 5.1). The same material and equipment used for visual recall in Conditions 2&4 of Experiment III were used. These included the video-camera, the TV monitor and VCR to record subjects' responses. In addition, recall sheets, each containing a blank 4x4 square matrix, were used for the subject to draw their mental image of the path. These recall sheets were obtained by printing a 'hypercard' with a 4x4 matrix on it. The matrix was the same as the matrix used in presentation of the task and the starting square was marked with a cross. A new recall sheet was used for every trial and a pen was provided for drawing.

This experiment involved four interference conditions: control, simple tapping, regular spatial tapping, and random spatial tapping. Each condition involved 3 experimental trials preceded by 1 practice trial. In addition, during the initial introduction of the matrix task to the subject, a practice trial was administered to demonstrate the primary task. Hence, the total number of trials that were administered was 17 trials and, thus, 17 Brooks sequences (tests) were needed. In Experiment III, only 8 'shortened' Brooks sequences were used. Hence, 9 additional tests (sets of 8 spatial directions) were developed and, as with previous tests, in no set were the same 'directions' given more than two times in sequence (see Appendix 5.2).

These nine sequences were presented visually on a computer screen as sequences of 8 displays. As in Experiment III, conditions 3&4, each display showed a 4x4 square matrix (10x10cm) with only one X in the centre of the successively designated square through which the path is moving. The same procedure used in Experiment III, Condition 3, to transform each sequence of 8 spatial statements into a sequence of 8 displays and to programme and script the HC application to present each sequence, was followed in presenting the additional 9 tests.

Thus, 17 'shortened' Brooks tests (sets of 8 statements) were transformed into 17 sequences of 8 displays to be visually presented to subjects on a computer screen with each display being presented at the rate of 2.5 seconds. Each test showed a path through the squares of the matrix and the task was visually recalled by drawing a line on a real matrix representing the mental image of the path shown. Subjects' responses and comments were video-recorded for subsequent analyses.

The secondary tasks:

Three secondary movement tasks were used and each was carried out during a maintenance interval of 30 seconds after which subjects recalled the primary visuo-spatial material. These tasks were:

1) Regular spatial tapping

This task was the same as the spatial tapping task used in Experiment 2-a with some modification regarding the material and equipment used. This task is based on the task used by Farmer et al (1986) and subsequently used by others. As explained in Experiment 2-a, it involves continuous sequential tapping of targets in space and has been used as a spatial suppression task. Since it is indicated to have a large motor component and involves holding a number of spatial locations in memory, it should utilise the resources of the VSSP. In Experiment 2-a, the apparatus for this task consisted of 4 metal plates (7x7cm) which were positioned in a square arrangement on a (23.5x38cm) horizontal board with 2.5cm separation between adjacent plates. Also, a 4-Channel Event Recorder was used. This machine uses a roll of thermal paper for recording responses which, when the machine is operated, runs at the speed of about 7.5mm per second. A metal-tipped stylus and the Event Recorder were both electrically connected to the apparatus so that if it is operated, whenever the stylus contacted each of the 4 plates, the touch is immediately recorded on the thermal paper by the corresponding channel in the Event Recorder. Each of the metal plates is connected to a corresponding channel so that plate 1 is connected to channel 1, plate 2 is connected to channel 2, and so on. Each channel has a corresponding space on the roll of thermal paper which enabled recording the tapping on each of the 4 plates. The stylus was used in tapping and the inter-tap intervals were recorded using this Event Recorder. A hard-board screen was mounted on two retort stands and placed in front of the subject so as to prevent him (her) from seeing the tapping targets.

The above apparatus appeared to have the following problems:

- Recording of tapping performance by the Event Recorder was not very accurate.

-Turning the Event Recorder on and off during testing and adjusting the thermal paper at every trial was distracting and time-consuming for the experimenter.

-Analysing the tapping data was a time-consuming task which involved measuring in mm the inter-tap intervals.

Hence, to avoid these problems, a 'computerised' version of the tapping apparatus was designed using the following material and procedure:
A Macintosh Quadra 660AV computer with a HC application was used. A HC stack was created with one card which was expanded to fill the whole computer screen. Four HC buttons were then created and made in square shapes, each was 6.5x6.5cm. These square buttons were then positioned on the card in a square arrangement with 2.5cm separation between adjacent buttons. These 4 buttons are intended to serve the same function as the 4 plates in the original apparatus round which the subject taps in turn in a clock-wise direction using a stylus. Each one of the 4 buttons was then 'scripted' so that whenever the mouse touched it, a sound was emitted and the time is recorded in a file. To make the new computerised version of the task similar to the original version, the sound of the metal-tipped stylus touching a metal plate in the original device was recorded and built into the HC stack and this sound was named "metal". So whenever the mouse touches any of the 4 square buttons, a sound is emitted to mark each touch and the time is recorded. The script of each of the 4 buttons is shown in Appendix 5.3.

Each of the buttons was named. The left button on the top row was named button (a) and the button to its right was named button (b), the right button on the bottom row was named button (c) whilst the button to its left was named button (d). To summarise, when the 'mouse' touches any one of the 4 square buttons, a sound is emitted and the name of the button and the time are recorded in a file. HC records time in ticks and a tick equals 1/60 of a second. For instance, if one uses the mouse to click on button (a), then the name of this button and the time are recorded in the file, and if button (b) is then clicked on, then the name of this button and the time are recorded. The difference between the two times is the interval between the two clicks (taps).

As indicated above, the name of each button and the time are recorded in a file whenever each button is 'tapped'. This file recording was achieved by scripting the HC stack to create a new file whenever it is opened and ask for a name for the file, e.g. the subject's number. For subsequent data analysis, this file could later be opened as a Microsoft or a Systat document. The script of the stack to create a data file for each subject is shown in Appendix 5.3.

During 'tapping' round the 4 square buttons which are arranged over the 'card', if the subject misses a button he (she) will hit the card over which the buttons are positioned. In the original apparatus, if the subject misses one of the metal plates, he (she) will hit the board over which the four plates were positioned. To make the new version similar to the original apparatus, the sound of the metal-tipped stylus in the original apparatus hitting the board instead of a metal plate was recorded and built into the HC stack and was named "board". Thus, if the subject misses a tapping target (a button) and hits the card over which the buttons are arranged, then this 'board' sound will be emitted. In addition, the name of the card and the time will be recorded in the tapping data file to indicate that the subject actually tapped but missed the target. The card was assigned the *short name* (M) to indicate a 'Miss'. The script of the card used to accomplish this is shown in Appendix 5.3.

So far, this computerised tapping apparatus looks like the following: When the relevant HC stack called "Tapping" is opened, a dialogue box appears on the computer screen asking for a subject number to be the name of the to be created tapping data file. Then, the card appeared filling the whole computer screen and over which the 4 square buttons were positioned in a square arrangement. If any button is touched by the *mouse*, a 'metal' sound is emitted and the name of the button and the time are recorded in the file. If the same or another button is then touched by the mouse, the name of the button and the time are again written in the data file. The difference between the two times is the interval between the two 'taps'. If a button is missed and the card was clicked on instead, then a 'board' sound is emitted so the subject realises that he (she) missed the tapping target. Also, if the 'return' key on the keyboard is pressed, then a space is left in the current file. This is to be used by the experimenter during testing. For instance, when a trial is completed, the experimenter presses the 'return' key which results in a space being left between the tapping data of the current and the next trial. This was simply for the purpose of distinguishing between the tapping data of various trials and the script used to achieve this is shown in Appendix 5.3.

A problem with the design of this computerised apparatus so far was that during testing the subject is not supposed to see the tapping targets and thus it would be difficult to carry out tapping using the mouse since the subject will not be able to determine its precise location on the screen without visual feedback. In addition, the mouse is not very accurate since there is a delay in recording the interval between each click and the other and thus the taps will not be recorded when the intervals between them are very short (.5 second). To solve this problem a Wacom Digitiser, made by Wacom Co Ltd, was used and it consists of the following (see Appendix 5.1):

UD-0608-A Tablet:

This is an Apple Desktop Bus (ADB) input device. The physical size of the entire tablet is 13(W) x 9.6(D) inches and the active area of the tablet is 8(W) x 6(D) inches. The active area is covered by a *transparent overlay* under which a paper could be placed. The tablet also has a cable called an ADB Connector which plugs into the ADB port of the Macintosh. This cable could be plugged into the keyboard instead of the mouse's plug.

UP-201 Stylus:

This is a cordless pressure-sensitive stylus. The size of the stylus is 5.5(L) x 0.4(D) inches. The stylus has a tip switch which is pressure-sensitive and is activated by pressing it down on the tablet's surface.

The digitiser alternates continuously between transmit and receive mode (changing modes about every 20 microseconds). In transmit mode, the tablet sends a signal to the stylus. The stylus stores energy from the signal. When the tablet goes into receive mode, the stylus sends a signal that carries switch and pressure data to the tablet. The tablet computes the location of the stylus and sends this information to the computer.

After the necessary software was installed on the computer, the tablet's cable was plugged into the keyboard instead of the mouse. The active area of the tablet corresponds to the computer screen and the stylus could be used to do the same functions of the mouse. If the stylus is used, for instance, to press on the upper left of the active area, then it is also pressing or clicking on the upper left of the computer screen. A copy of the 'card' with the 4 square buttons arranged over it was then printed. This paper copy, which merely consists of 4 squares positioned in a square arrangement, was then placed under the transparent overlay of the tablet. This transparent overlay covers the active area of the tablet. The copy was then adjusted so that each square matched its corresponding square (button) on the computer screen so that if, for instance, square (a) on the tablet is tapped by the stylus it is also tapped on the computer screen and the 'metal' sound is emitted and the data are recorded in the relevant data file. Hence, now the cordless stylus could be used to tap round the 4 squares on the tablet. This stylus is so sensitive that it records the interval between one tap and the other even it is as short as 1 tick. Again if the subject misses a target and taps any where else on the transparent overlay, the 'board' sound is emitted. In this context, the transparent overlay which covers the active area of the tablet corresponds to the entire computer screen.

During testing, the tablet was placed on the tabletop in front of the subject and a hard-board screen mounted on two retort stands was placed in front of the subject so as to prevent them from seeing the active area of the tablet (the 4 tapping targets). The subject was thus making unseen sequences of arm movements. The subject's task was to tap, using the cordless stylus, round the 4 squares in turn in a clockwise direction whenever they heard an auditory signal. This signal was a 'simple beep' recorded on an audiocassette from a Macintosh Plus computer using the application HC. The experimenter programmed HC to emit and repeat the 'beeps' at a regular interval of 1 second for the desired length and the HC script is shown in Appendix 5.3. The beeps were then played from a tape-recorder. Hence, in this spatial tapping task the subject tapped round the 4 square targets, positioned in a square arrangement, in turn in a clockwise direction at the regular rate of 1 tap per second.

2) Random spatial tapping:

This task was the same as the above spatial tapping task except one important modification. Instead of tapping round the 4 square targets in response to a regular signal, the subject tapped in response to an irregular signal. This irregular signal was generated randomly by the HC application at variable intervals ranging from 0.5-1.5 seconds. This was accomplished using the *Random Function* in HC. The HC script for obtaining these random signals (beeps) is shown in Appendix 5.3.

According to this script, a beep is emitted after a minimum interval of 30 ticks and a maximum interval of 90 ticks. A tick in HC equals 1/60 of a second. This was done to ensure that the mean of the intervals randomly generated over a longer period will be 60 ticks (1 second) which is equal to the rate of the other tapping conditions. As can be seen in the script, HC was scripted as follows: *wait 29 ticks + random(61)ticks, beep.* This resulted in HC waiting 29 ticks plus a random number of 1-61 ticks making the minimum possible inter-beep interval 30 ticks and the maximum possible interval 90 ticks. HC was then programmed to repeat the above random auditory signal for the desired length of time. These signals were then recorded from the computer on an audiocassette to be used with all subjects in this tapping condition.

This random rate of tapping is different from the rhythmic rate used in Experiment II. In that experiment, HC was programmed to emit the signal at a fixed rhythmic sequence of intervals which was: 25, 60, 100, 55 ticks, and to repeat this sequence for the desired length of time. This fixed rhythmic sequence of signals could, in some cases, be learned by the subject whereas the current random sequence of signals is almost impossible to learn since the intervals are simply random. Although both the rhythmic and random sequences of signals were assumed to require concentration and attention from the subject, it was presumed that the random sequence would require greater concentration and thus greater CE involvement.

The regular and random spatial tapping tasks have the same spatial component which is tapping round 4 targets in turn in a clockwise direction. However, the random tapping task has an extra component which is unpredictability of the rate of tapping which is assumed to load the CE (see chapter 1). The irregular rate of tapping is assumed to demand concentration and attention when anticipating the signals and making judgements regarding when to tap and when to pause.

3) Simple tapping:

The same apparatus used for the above two tapping tasks was used for this task. Unlike the above two tasks, subjects in this task tapped only one single target which was square (c) in the apparatus. If the subject was left-handed, square (d) was used. Subjects tapped this target in response to the same regular signal used with the regular spatial tapping which was at the rate of 1 signal per second.

In addition to the material and equipment used in the above three conditions, a stopwatch was used to time the maintenance interval, and a clipboard was used over which each recall sheet was placed prior to being handed to the subject.

B) Subjects

16 participants (8 males & 8 females) were recruited from undergraduate & postgraduate students at Warwick University and took part in this experiment. Their age ranged from 18-37 with a mean of 21. None had participated in any of the previous experiments. Each subject was tested in one session and was offered a fee of £3. The session lasted approximately 80-90 minutes and this included, in addition to the introduction of the tasks and the actual testing, providing comments on the experimental conditions and answering the VVIQ.

C) Design & procedure

A within subjects repeated measures design was used with the four interference conditions as the within subjects repeated measures variables. Subjects were tested individually and each took part in all of the experimental conditions. The primary visuo-spatial task used was the 'simplified' visually presented and recalled version of the Brooks Matrix. This experiment examined movement interference effects on maintenance of this primary task during a retention interval of 30 seconds. This interval was either unfilled or filled with one of three movement tasks which were: simple tapping, regular spatial tapping, and random spatial tapping. Hence, this experiment involved four experimental conditions: control (no interference), simple tapping, regular spatial tapping, and random spatial tapping. Details of these conditions will be provided in the testing procedure section.

The order of administering these 4 interference conditions was counterbalanced across subjects according to a 4x4 Latin square design. The 8 possible orders of the 4 interference conditions were presented to the first 8 subjects and then to the last 8 subjects. There were 17 tests (sets of 8 displays of the matrix). The first test was always used as a practice trial during the initial introduction of the matrix task to the subject. The remaining 16 tests were divided into 4 blocks of 4 tests. In each block, the first test was always used for the practice trial on the current interference condition whereas the remaining 3 tests were used for the 3 experimental trials in that condition. The first block of tests was always used for the first interference condition to be administered, the second block was always used for the second interference condition to be administered, and so on. The order of administering the four interference conditions was counterbalanced across subjects according to a Latin square design. This procedure was aimed at ensuring that each interference condition appeared an equal number of times under each block of tests, ensuring that any peculiarities of a particular block were not associated with a particular interference condition.

Experimental set-up:

The subject was seated at a rectangular table. The experimenter sat at the left end of the table which is located on the left hand-side of the subject so as not to be facing the subject. In front of the experimenter, a 30cm-high x 45cm-wide wooden stand was placed on the tabletop in order to hide the test material (e.g. the recall sheets) from the sight of the subject. The MacPlus computer used to present the primary task was placed on the tabletop facing the subject, approximately 0.60 metre away from the subject's eye position (see Appendix 5.1). The mouse was placed on the table within the experimenter's reach so as to be able to operate the presentation of each Brooks test. The tapping apparatus, which consists of the Wacom Tablet with a sheet of paper containing the 4 tapping square targets placed under its transparent overlay, was also placed on the table in front of the subject, between the subject and the computer. The cordless stylus was placed within the reach of the subject. In addition, a hard-board screen installed on two retort stands was placed in front of the subject in such a way as to prevent the subject from seeing the tapping targets during tapping. That is, this screen was positioned in such a way as to conceal the tapping device from visual inspection during testing. The tapping device (the Tablet) was connected to the keyboard of a Quadra 660AV Macintosh computer. This computer was placed to the left hand-side of the subject approximately 2 metres-away from the subject's seat. This computer rested in an angular background position so that the subject cannot see the computer but can easily hear the sounds emitted by the computer during tapping. The keyboard of this computer was also placed within the reach of the experimenter since after each tapping trial the experimenter had to press the *return* key so that a space was made in the tapping data file which enabled distinguishing the data of each trial. A stopwatch and a tape-recorder were also placed on the tabletop near the experimenter. The stopwatch was used to time the maintenance interval whilst the tape-recorder was used, during the tapping conditions, to play the auditory signals. A pen was placed on the table for the subject to use during recall to draw a representation of their image of the path on a real matrix. The video-camera was installed on a tripod at the right hand-side of the subject and was adjusted so that it overlooked the subject when he (she) drew a line representing their retained mental image of the path on the recall sheet. The VCR and the video-monitor were placed within the reach of the experimenter so as to be able to operate and monitor the recording of subjects' responses and comments.

Testing procedure:

Introduction of the tasks:

The testing session began with introducing the matrix task and the tapping apparatus to the subject before the tasks were combined in any interference condition. At first, the subject was initially introduced to the 'simplified' variant of the Brooks Matrix. He (she) was shown a 4x4 square matrix (10x10cm) with the starting square marked, which was a copy of the matrix used to present the task on the computer screen. The subject was then told that he (she) will see a set of 8 consecutive displays of the matrix on the computer screen that show a path within the squares of the matrix. Subjects were shown how the displays related to the matrix and were informed that the path always began from the same starting square (second cell on the second row). Hence, it was indicated that the first display will always show an X in the starting square whereas the other 7 displays will show the same X moving successively in adjacent squares around the matrix. Subjects were shown how such displays related to the matrix. It was explained that the only way in which tests (sets of 8 displays) differed was the sequence of transitions (up, left, down, right) from one square to another. Thus, tests differed only in regard to the *direction* of the path through the matrix.

Subjects were instructed that after presentation of each test (8 displays), they will be presented with a recall sheet containing a real 4x4 matrix, and that the task was to recall the path by drawing a line on the matrix representing their mental image of the path shown on the screen. The subject was instructed to attempt to remember each path by forming a mental image of the path within the squares of matrix, and that this image could then be used to help in recalling the path. A practice trial was then given to familiarise the subject with the 'simplified' variant of the matrix task. This practice trial involved no interference task. The first test of the 17 tests was always used for this introductory practice trial. During this trial, the subject watched the first sequence of 8 displays of the matrix on the computer screen which showed a path around the matrix. After the 8 displays had been shown, a recall sheet was handed to the subject whose task was to draw a line on the matrix representing his (her) mental image of the path (see Appendix 5.1).

After the matrix task had been demonstrated to the subject, he (she) was then introduced and familiarised with the tapping apparatus. Subjects were shown the 4 tapping targets and the cordless stylus and were asked to try tapping round the targets in a clock-wise direction. They were informed that during actual testing, the targets will be concealed and that tapping will be in response to auditory signals. A demonstration of the signals was played from the tape-recorder. Subjects were also briefed on how the other computer recorded the tapping data including the time intervals between each tap and the other. Following this introduction, each subject was allowed to practise tapping round the targets until he (she) made at least two-minutes of errorless unseen tapping which meant not missing any target in the indicated sequence.

Testing Steps:

Testing began after the introduction of the primary task and the tapping apparatus to the subject. This experiment involved 4 movement interference conditions during a maintenance period of 30 seconds. Each condition was introduced to the subject and the subject was given detailed instructions and a practice trial on the current condition before being given 3 testing trials. This procedure will be explained in the next section. As explained in the design section, the 4 interference conditions were administered in a counterbalanced order across subjects according to a Latin square design. One of the interference conditions was a control condition in which the maintenance period was unfilled. In the other 3 conditions the maintenance period was filled by one of 3 movement tapping tasks. Testing in each of these 4 conditions took the following procedure:

1) Control (no interference) condition:

If this condition was to be administered first, it was preceded by an introduction to the matrix task as outlined above. Testing in this condition was as follows: it was explained to the subject that recall of the path would be after an interval of 30 seconds which starts immediately after the last display of the matrix had been presented on the screen. The subject was instructed that during the retention interval he (she) is requested to do nothing other than to try to remember the path through the matrix. The subject was also informed that after the 30 seconds interval, a recall sheet placed on the clipboard will immediately be handed to him (her), and that the task is to draw a line on the matrix representing their mental image of the path. A practice trial was then given using the first test of the current block of 4 tests. Then 3 experimental trials were administered using the remaining 3 tests in that block. All other procedures were similar to those outlined in the introduction of the tasks section.

2) Simple tapping condition:

In this condition, subjects were asked to carry out a simple tapping task during the maintenance interval. If this condition was to be administered first, it was preceded by an introduction of the subject to the matrix task and to the tapping apparatus as outlined above. Testing followed the same procedure used with the control condition except regarding the tapping instructions. Subjects were informed that recall of the path will be after an interval of 30 seconds and that during this interval they are requested to carry out a tapping task whilst also trying to keep remembering the path through the matrix. They were informed that during the retention interval the experimenter will play the auditory signal and that task is to tap, using the stylus, on the indicated single target (square) every time they heard the signal which was at the rate of 1 signal per second. Subjects were instructed and encouraged to tap in time to the signal and try not to miss the tapping target. They were also told to stop tapping when the signal stops at the end of the 30 seconds interval.

Subjects were also instructed about the dual-task nature of the experiment and that they should treat the two tasks equally by trying not to concentrate on one more than the other. Prior to the practice trial on this condition, subjects were asked to practise some simple tapping on its own in response to the signal for 2 minutes or until they indicated readiness to begin the trials. A practice trial on this condition was then administered using the first test of the current block of tests. This practice trial took the following procedure: The experimenter clicked, using the mouse, on the button of the current 'matrix test' so the test was presented on the computer screen. The subject watched the 8 displays of the matrix whilst holding the stylus in his (her) hand. As soon as the presentation of the 8 displays had been completed, the retention interval immediately commenced and the experimenter played the regular signal and the subject began tapping on the single target in response to the signal. At the end of the 30 seconds retention interval, timed by a stop-watch, the experimenter stopped the signal and hence the subject stopped tapping. Then, a recall sheet, placed on the clipboard, was immediately handed to the subject whose task was to draw a line on the matrix representing his (her) mental image of the path. The pen used to draw the line was always placed on the table in front of the subject. After this practice trial, 3 testing trials were administered following the same procedure used to administer the practice trial. Photographs illustrating the testing procedure are provided in Appendix 5.1.

3) Regular spatial tapping condition:

If this condition was to be administered first, it was preceded by an introduction of the subject to the matrix task and to the tapping apparatus as outlined in the introduction of the tasks section. Before testing began in this condition, subjects were allowed to practise the regular spatial tapping on its own in response to the regular signal for 2 minutes or until they indicated readiness to begin the trials. Subjects who showed a tendency to miss the targets were given extra practice until their tapping improved and no error was observed. Then a practice trial on the combined two tasks was administered using the first test of the current block of 4 tests followed by 3 testing trials using the remaining 3 tests in that block. The same steps, procedures, and instructions used to administer the simple tapping condition were used to administer this condition with one exception regarding the tapping instructions. Subjects in this condition, which involved movements to targets in space during the retention interval, were instructed to tap, using the stylus, round the 4 tapping targets in turn in a clockwise direction and in response to the regular auditory signal. They were instructed to tap each square in its turn every time they heard the signal which was at the rate of 1 signal per second. Subjects were instructed to tap in time with the signal and to try not to miss any target. They were asked to stop tapping when the signal stopped at the end of the 30 seconds interval. Subjects were encouraged to hit the targets accurately in the indicated sequence every time they heard the signal. They were also instructed on the importance of treating the two tasks equally. During testing, the experimenter monitored the tapping performance visually and subjects who showed a tendency to miss the tapping targets were warned of this between trials.

4) Random Spatial Tapping condition:

If this condition was to be administered first, it was preceded by an introduction of the subject to the matrix task and to the tapping apparatus as outlined in the introduction of the tasks section. Before testing began, subjects were allowed to practise the random spatial tapping on its own in response to the irregular signal for 2 minutes or until the subject indicated readiness to begin the trials. Subjects who showed a tendency to miss the targets or the random signals were given extra training until their tapping has improved and no error was observed. Then a practice trial on the combined two tasks was administered using the first test of the current block of 4 tests followed by 3 testing trials using the remaining 3 tests. The same procedures and instructions used to administer the simple tapping condition were used to administer this condition with one exception regarding the tapping instructions. Subjects were instructed to tap, during the interval, round the 4 tapping targets in turn in clockwise direction and in response to the random auditory signal. They were instructed to tap each square in its turn every time they heard the signal which was at variable intervals ranging between .5 and 1.5 seconds. Subjects were instructed to tap in time to the signal and try not to miss any target. They were instructed to stop tapping when the signal stopped at the end of the 30 seconds interval. Subjects were encouraged to hit the targets accurately in the indicated sequence every time they heard the signal. As in the other conditions, during testing the experimenter was vigilant for potential non-compliance with the tapping instructions and subjects who showed a tendency to miss the tapping targets or the random signals were warned of this between trials.

Hence, this experiment examined the effects of various movement tasks on maintenance of the 'simplified' variant of the Brooks Matrix. This maintenance stage was either unfilled or filled with one of three tapping tasks. Subjects were introduced and trained on the primary and secondary tasks before they were combined. Responses were video-recorded and subjects were made aware of this recording and of the limit-free response time. A specific set of instructions was prepared for each interference condition and used with all subjects (see Appendix 5.4). As in the SB procedure, no specific knowledge of results was given to subjects but they were periodically encouraged about their performance. Subjects answered the VVIQ (see chapter 2 & Appendix 1.2) subsequent to testing.

6.3. Results

Subjects responded to the memory task by drawing a line on a real matrix representing their mental image of the path shown by the 8 displays. Performance was measured by the number of the correctly recalled 'spatial' bends in the line drawn by the subject. Errors were counted for each subject in every condition and an error refers to any incorrect bend in the line drawn on the matrix. Each bend in the line represents one of the 8 spatial directions (starting square, up, left,...) respectively. Each line drawn started from the starting square and changed direction according to each sequence of 8 displays (test). Thus, any bend in the line which does not match its corresponding spatial direction was considered an error. In each trial, 8 'displays' had to be recalled. The first display involved no 'spatial direction' and was always the same starting square and thus involved no error. There are therefore 7 possible errors in each trial and since each subject was given 3 experimental trials in each condition, there are 21 possible errors per subject in each condition. Table 6.a shows the mean percentage of error at each interference condition. Figure 6.1 illustrates these data:

Interference condition	Mean	N	SD
No interference	1.81	16	3.86
Simple tapping	3.86	16	6.76
Regular spatial tapping	2.38	16	4.24
Random spatial tapping	10.43	16	14.48

Table 6.a. Mean percentage of error at each interference condition during the maintenance stage of the 'simplified' variant of the Brooks Matrix task.

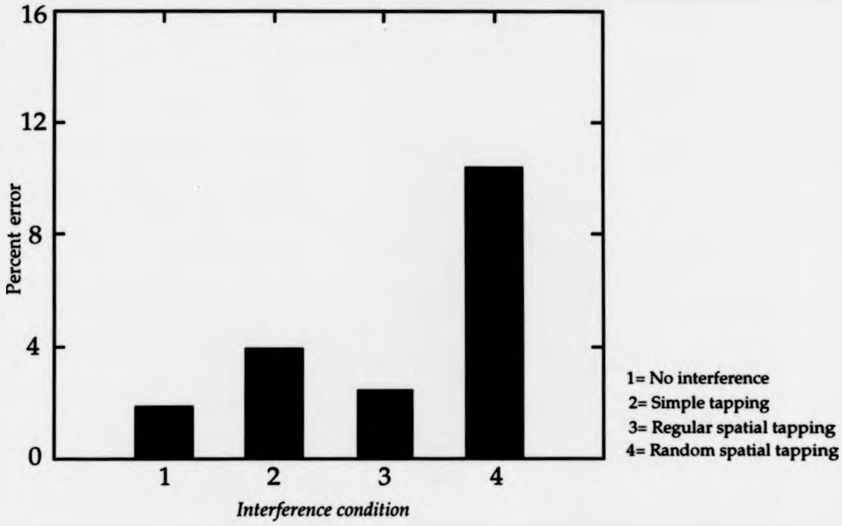


Figure 6.1. Mean percentage of error at each movement interfrence condition.

The above data were analysed using a one-way within subjects ANOVA with the four conditions as the repeated measures variable. The ANOVA showed a significant main effect of interference condition [$F(3,45)=3.99$; $p=0.01$]. There was some indication that the sphericity assumption was not strictly true, a Greenhouse-Geisser correction still yielded a significant difference (epsilon= 0.54, $p=0.04$). Tukey tests indicated that the only significant differences between means were between conditions 1 and 4 ($p=0.02$) and between conditions 3 and 4 ($p=0.03$). All other pairwise comparisons were nonsignificant. Random spatial tapping interfered with maintenance of the visuo-spatial material. However, simple tapping and regular spatial tapping did not interfere with maintenance as both conditions did not differ from the no interference condition ($p=0.88$, $p=0.99$ respectively). Hence, only a secondary task that loads the CE interfered with maintenance of the path whilst a spatial task led to no interference.

An analysis of the SP effect was carried out on the data in order to find out the nature of the SP curve and whether more errors were made at the primary or at the most recent items. Errors made at each of the 8 serial positions were counted. 16 subjects were tested and each was given a total of 12 experimental trials, therefore each SP had 192 chances of being error. Figure 6.2 shows the mean percentage of error at each SP.

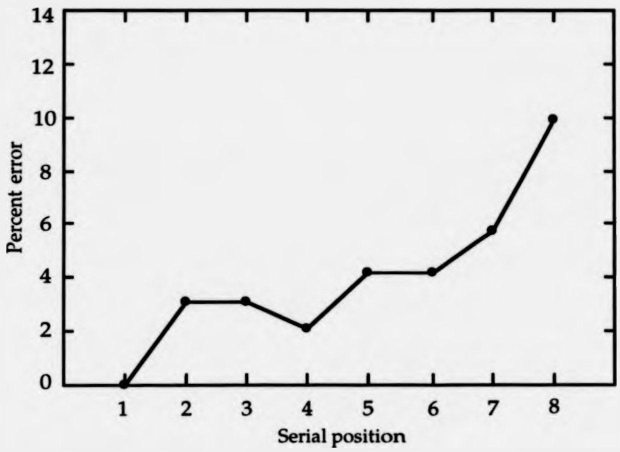


Figure 6.2. The SP curve showing the mean percentage of error at each SP.

No errors were made at the first SP since each path always began from the same starting square. Hence, position 1 was excluded from the statistical analysis. A one-way within subjects ANOVA was performed on this SP data with positions 2-8 as the repeated measures variable. The ANOVA showed a highly significant main effect of SP [$F(6,90)=6.07$, $P=0.00$]. More errors were made at some positions than others. The above curve shows that error rate increased approximately linearly with SP. This pattern indicates a primacy effect and a 'negative' recency effect.

Regarding the VVIQ, subjects' ratings on the VVIQ were correlated to the total numbers of errors they made on the matrix task under the four conditions in order to examine whether vividness of visual imagery correlates with performance. A Spearman correlation test showed a significant positive correlation between ratings on the VVIQ and the overall performance on the matrix task ($rho=0.55$, $p<.05$).

<u>**Secondary-task data:**</u>

In each of the 3 tapping conditions, subjects tapped either at the fixed rate of 1 tap per second or at a variable rate ranging from a minimum of 0.5 and a maximum of

1.5 seconds. As explained in the material section, every time the subject tapped, the computer recorded the time in the relevant subject file. Hence, for each trial the computer recorded the times at which the subject tapped. To obtain the time intervals between each tap and the other under each trial, the time of each tap was subtracted from the time of the tap that preceded it which resulted in a set of tapping intervals under each trial. Ideally, for simple and regular spatial tapping, each of these time intervals should be equal to 60 ticks (1 second) since subjects were supposed to tap at the fixed rate of one tap per second during the 30 second maintenance period. For the random tapping condition, these time intervals should ideally range between 30-90 ticks with a mean of 60 ticks. The following is an analysis of the tapping data under each condition:

1) Simple tapping:

In this experiment, 16 subjects were tested and each was given 3 testing trials under each condition. Thus, under each condition there were 48 trials. Tapping intervals under each trial were calculated following the above procedure. Subjects were supposed to tap in this condition at the rate of 1 tap per second during the 30 seconds maintenance interval. Hence, to show compliance, the obtained intervals under each trial should be about 29 intervals with a mean close to 60 ticks (1 sec) and a very small SD. However, in some trials if the subject, for instance, missed just one tap this results in one of the intervals being so large and that also makes the SD so large despite the fact that the subject was otherwise tapping in time with the stimulus. This problem is related to one of the properties of the SD which is the fact that the SD is sensitive to each score in the distribution. If a score is moved closer to the mean, then the SD will become smaller, conversely, if a score shifts away from the mean, then the SD will increase. To solve this problem, the Median of the Absolute Deviations from the mean (MAD) was used instead of the SD. Calculating the MAD involves subtracting the time intervals under each trial from their *mean* and treating the outcomes as absolute values and then calculating the *median* of such values or deviations. In general, the median is a statistic that is not as sensitive to extreme values as the mean and SD and it is the value above which half the data falls and thus it is more typical of the majority of the numbers. This is why the median is often used for representing skewed data such as incomes or reaction times. For instance, Logie & Salway (1990) used the median when the characteristics of one set of their data indicated that the means were inappropriate. In such set of data, outliers were fairly common. In our case, the MAD is the value above which half of the absolute deviations from the mean fall and is more typical of the majority of the deviations from the mean. The MAD was calculated for each of the 48 trials in this condition using the Math function of the Systat application. For example, the MAD for trial 1 was calculated as follows:

Let variable: trial 1 Absolute Deviations= ABS(trial1-$\bar{X}$)

This results in a new column being created in the data file containing the absolute deviations from the mean for trial 1. Then, simply the Median of these Absolute Deviations from the mean is calculated and treated as the SD since it will give a more accurate picture of the dispersion of the majority of the scores relative to the mean. Table 6.b shows the mean inter-response interval and the MAD for each trial in this condition.

Subj-Trial	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	4-3
Mean	62.12	63.67	62.18	62.24	61.21	65.12	61.07	60.43	61.07	65.19	66.46	68.35
M.A.D.	2.89	3.67	3.68	3.24	2.21	5.62	2.50	2.57	5.07	4.00	2.53	3.35
Subj-Trial	5-1	5-2	5-3	6-1	6-2	6-3	7-1	7-2	7-3	8-1	8-2	8-3
Mean	72.32	60.17	58.52	60.14	63.50	61.29	61.72	60.39	63.59	61.59	60.82	61.14
M.A.D.	13.32	2.83	3.48	2.86	2.50	2.50	1.28	2.39	2.59	1.59	2	1.86
Subj-Trial	9-1	9-2	9-3	10-1	10-2	10-3	11-1	11-2	11-3	12-1	12-2	12-3
Mean	60.79	60.86	60.52	67.27	60.29	61.17	62.04	61.32	61.32	62.46	61	60.17
M.A.D.	3.21	3.86	2.52	5.27	3.29	2.83	1.50	1.32	1	3.46	2	1.83
Subj-Trial	13-1	13-2	13-3	14-1	14-2	14-3	15-1	15-2	15-3	16-1	16-2	16-3
Mean	63.33	61.43	61.50	60.69	61.68	62.48	60.68	60.61	60.43	61.07	65.93	60.82
M.A.D.	3.67	3.43	3.50	2.69	4.18	3.48	2.50	3.93	3.43	2.07	4.93	1.82

Table 6.b. Mean inter-response interval and the median of the absolute deviations from the mean at each trial in the simple tapping condition.

In this condition, the closer the mean to 60 ticks and the smaller the SD, the more the subject was performing to the criterion. Hence, it was considered that, in any trial, if the mean is close to 60 ticks with an MAD (SD) that is smaller than 5.00 then the subject was reasonably tapping to the criterion. As can be seen in table 6.b, and according to this rough criterion, only in 4 trials was there no compliance with the tapping rate whilst in the remaining 44 trials, subjects were tapping close to the rate of 1 tap per 60 ticks. Thus, it could be concluded that in the majority of trials in this condition, subjects were complying with the tapping instructions.

2) Regular Spatial Tapping

In this condition, subjects were supposed to tap round the 4 targets at the fixed rate of 1 tap per 60 ticks. The same procedure followed in calculating the mean and the MAD for simple tapping was followed in calculating the mean and the MAD for each trial in this condition. Table 6.c shows the mean inter-tap interval and the MAD for each trial:

Subj-Trial	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	4-3
Mean	62.44	67.54	59.90	68.23	61.50	61.68	65.82	61.90	59.21	59.36	63.62	57.06
M.A.D.	1.56	4.54	3.90	7.73	2.50	2.32	3.82	2.10	4.21	3.50	3.38	3.06
Subj-Trial	5-1	5-2	5-3	6-1	6-2	6-3	7-1	7-2	7-3	8-1	8-2	8-3
Mean	61	55.74	58.23	60.57	60.17	58.56	63.90	60.03	61.55	61.39	61.43	61.03
M.A.D.	4.00	4.26	2.77	4.00	4.17	3.00	2.90	1.97	1.55	1.61	1.57	2.00
Subj-Trial	9-1	9-2	9-3	10-1	10-2	10-3	11-1	11-2	11-3	12-1	12-2	12-3
Mean	61.59	57.60	59.90	59	61.37	59.97	56.48	59.20	55.78	60.78	60.86	60.61
M.A.D.	2.59	7.40	3.90	5.00	3.37	1.97	2.52	2.80	5.72	1.50	1.86	1.39
Subj-Trial	13-1	13-2	13-3	14-1	14-2	14-3	15-1	15-2	15-3	16-1	16-2	16-3
Mean	60.35	61.11	59.76	61.25	63.68	61.21	60.30	61.67	62.11	64.15	61.57	61.33
M.A.D.	2.66	4.11	3.76	1.25	3.18	0.79	3.30	3.67	4.89	2.85	1.57	1.33

Table 6.c The mean inter-response interval and the MAD at each trial in the regular spatial tapping condition.

As in the previous condition, the ideal mean of tapping intervals under each trial should be close to 60 ticks with a very small MAD (SD). Hence, it was considered that, in any trial, if the mean was close to 60 ticks with a MAD that is smaller than 5.00 then the subject was complying with the tapping instructions. As can be seen in table 6.c, only in 4 trials was there no compliance according to this rough criterion. Hence, it could be concluded that in the majority of trials, subjects complied with the instructions by tapping round the 4 targets at a regular rate.

3) Random Spatial Tapping

In this condition, subjects were supposed to tap round the 4 targets at a random rate ranging from 30-90 ticks. The same procedure followed in calculating the mean and the MAD for each trial in the simple tapping condition was also followed in calculating the mean and the MAD for each trial in this condition. Table 6.d shows the mean inter-response interval and the MAD for each trial:

Subj-Trial	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	4-3
Mean	59.41	58.09	69.37	67.44	102.58	101.78	63.52	64.29	69.61	56.57	63.97	70.57
M.A.D.	9.41	12.09	15.00	10.44	48.53	32.50	17.48	13.50	19.11	5.43	11.97	10
Subj-Trial	5-1	5-2	5-3	6-1	6-2	6-3	7-1	7-2	7-3	8-1	8-2	8-3
Mean	75.86	63.78	64.41	69.93	72.32	64.57	69.75	69.54	66.55	65.42	63.21	59.19
M.A.D.	15	14.5	16.41	13.07	14	16.07	17.75	18	16.55	16.42	15.79	11.81
Subj-Trial	9-1	9-2	9-3	10-1	10-2	10-3	11-1	11-2	11-3	12-1	12-2	12-3
Mean	61.58	62.17	68.62	65.56	65.43	66.30	68.50	59.27	56.57	65	63.43	70.20
M.A.D.	14.58	14.17	16.39	16.44	13.57	13.30	17	16.77	12	14.50	14.50	14.20
Subj-Trial	13-1	13-2	13-3	14-1	14-2	14-3	15-1	15-2	15-3	16-1	16-2	16-3
Mean	63.44	68.92	64.89	68	64.75	61.83	68.54	65.07	63.76	63.70	70.37	63.11
M.A.D.	14.44	13.08	14.11	15.00	8.25	13.83	9.50	12.43	13.24	14.30	16.37	15.89

Table 6.d The mean inter-response interval and the MAD at each trial in the random spatial tapping condition.

Tapping was in response to auditory signals randomly generated by a computer. The time intervals between these signals were randomly generated with a minimum of 30 ticks and a maximum of 90 ticks. Hence, the mean of tapping intervals under each trial in this condition should be close to 60 ticks with a MAD close to 15. This expected MAD was established by randomly choosing 30 numbers from 30-90 and then calculating their mean which was close to 60 and their MAD which was close to 15. Therefore, as an indication of compliance, it was considered that if the MAD in any trial was between 10-20 with a mean of no more than 75, then the subject was reasonably complying with the instructions to tap in time with the irregular signal. As can be seen in table 6.d, only in 7 trials was there no compliance according to this rough criterion whereas in the remaining 41 trials, subjects seem to have largely tapped in time with the random signal.

In order to find out if there is a relationship between compliance with the tapping instructions in these three conditions and performance on the primary task, the following analyses were conducted. In general, in dual task paradigms, data should be provided on performance of both components of a dual task condition so that it can be determined whether a decrement in performance of one task is merely the result of a trade for improvement in performance of the other (Heuer & Wing, 1984). In dual task paradigms, a common experience is that if neither task is performed very well, giving priority to one task to obtain an improvement in its performance is achieved at the cost of some deterioration in performance of the other (Barber, 1989; Heuer & Wing, 1984). In other words, if the primary and secondary tasks are difficult or if they share a common WM resource, then there will be a trade-off between performance on the two tasks. If there is an improvement in performance on the primary task, for instance, then there will be an accompanying decline in performance on the secondary task. If the two tasks do not share a common memory resource or if one task is too easy, then it might be observed that changes in performance on one task do not affect the level of performance on the other. In such task combinations, no trade-off between performance of the two tasks occur, varying the performance level in one task from near zero to the maximum has no effect on the performance of the other task. However, in such dual-task situations there is usually a cost of concurrence

(Navon & Gopher, 1979) associated with the introduction of a secondary task, even if that task is performed at a minimal level. A small decrement in performance occurs in each task in the dual-task situation relative to the performance level achieved in the single task case.

A key idea in resource theory (Navon & Gopher, 1979; Norman & Bobrow, 1975) as applied to dual task performance is that the pool of processing resources (attention, mental effort, processing capacity, or however else it is characterised) is limited in amount, and can be shared by more than one task or activity. Hence, in general, as more resources are devoted to a task, performance on it improves, and performance of a concurrent task deteriorates since less resources remain to be allocated to it. The relationship between performance on a task and resources supplied is called 'performance-resource function', and this function varies according to factors such as task difficulty and the emphasis to be placed on the task. The joint performance on two tasks can be derived from their performance-resource function, and the form of the function relating performance on pairs of tasks is called the *performance operating characteristic (POC)* (Norman & Bobrow, 1975). This derived function indicates any trade-off between performance on the two tasks. Points along a POC may be generated by, for instance, instructions to change the priority given to the two tasks. By manipulating the difficulty of one of the two tasks, a family of POCs may be obtained. For instance, making task Y easy enables combining it with moderately good levels of performance on task X whereas gradually making task Y more difficult will result in Y performance dropping below 100% until interference is demonstrated with further improvement in X.

To find out whether compliance with the tapping instructions correlates with performance on the matrix task, performance on the primary task in each interference condition was plotted as a function of performance of the secondary task in that condition. Performance of each secondary task was represented by the

MADs, obtained under all of the 48 trials, as indicators of compliance whereas performance on the primary task was represented by the numbers of errors made at all of the 48 trials in each condition. In general, if there is a trade-off between performance of the two tasks or if the secondary task led to interference, then the relevant plot should show that more compliance on the secondary task is accompanied by more errors on the primary task and vice versa. Figures 6.3a,b&c show the POC plots relating performance on the primary task to performance on the simple tapping, regular spatial tapping, and random spatial tapping tasks:

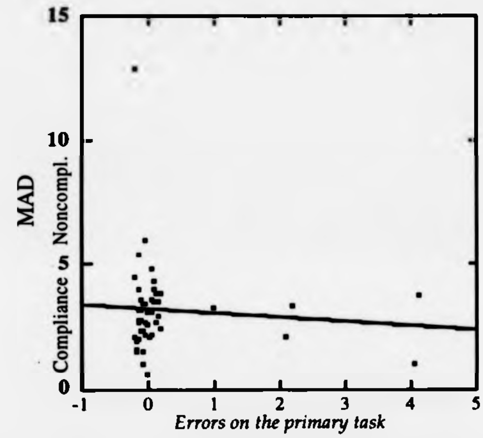


Figure 6.3a. Performance on the primary matrix task as a function of performance on the simple tapping task (48 trials).

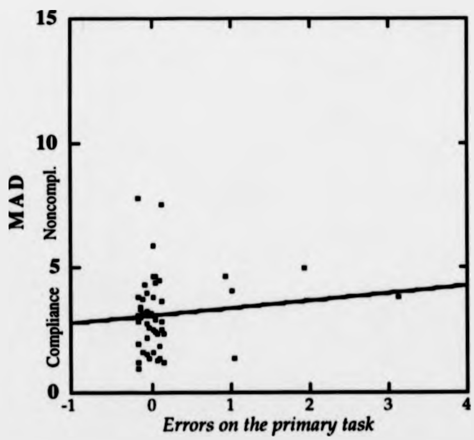


Figure 6.3b. Performance on the primary matrix task as a function of performance on the regular spatial tapping task (48 trials).

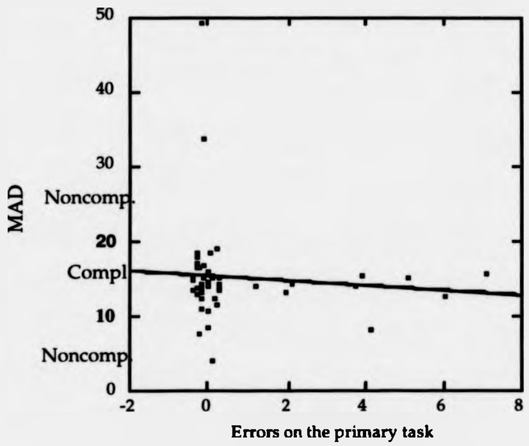


Figure 6.3c Performance on the primary matrix task as a function of performance on the random spatial tapping task (48 trials).

Regarding the simple tapping condition (figure 6.3a), only in 5 out of the 48 trials were errors made on the primary task which indicates a low level of interference by simple tapping (13 errors). In those 5 trials, subjects were also complying with the tapping instructions (MADs below 5) which might indicate some sort of a trade-off. However, the plot also shows that the overwhelming majority of the trials in which no errors were made on the primary task, fall in the compliance area of the plot. This indicates that complying with the tapping instructions does not necessarily lead to making errors on the primary task which in turn indicates no trade-off between performance of the two tasks. In this condition, if there is a trade-off, a negative correlation between performance of the two tasks should occur since it is expected that the smaller the MAD (more compliance) the more the errors on the primary task and vice versa. A Pearson correlation test was conducted on the data and showed no significant negative correlation between compliance with the simple tapping instructions and performance on the matrix task (r=-0.08), p=0.57).

Regarding the regular spatial tapping condition (figure 6.3b), the plot shows that only in 5 out of the 48 trials were errors made on the primary task which indicates a very low level of interference by the regular spatial tapping task (8 errors). In these 5 trials, subjects were also complying with the tapping instructions (MADs below 5) which might indicate some sort of a trade-off. However, the plot also shows that the overwhelming majority of the trials in which no errors were made on the primary task fall in the compliance area of the plot. This indicates that complying with the tapping instructions does not necessarily lead to making errors on the primary task which in turn indicates no trade-off between performance of the two tasks. In this condition, if there is a trade-off, a significant negative correlation between performance of the two tasks should occur since it is expected that the smaller the MAD (more compliance) the more the errors on the primary task and vice versa. A Pearson correlation test showed no significant correlation between compliance with the regular tapping instructions and performance on the matrix task (r=0.12), p=0.43).

Finally, regarding random spatial tapping (figure 6.3c), the plot shows that in 9 out of the 48 trials errors were made on the primary task which indicates a higher level of interference (35 errors). In all of these 9 trials, subjects were also complying with the random tapping instructions (MADs between 10-20) which might indicate a trade-off. Making errors on the matrix task in this condition seems to necessarily means that the subject was also complying with the tapping instructions. Trials in which there was no compliance (MADs below 10 or over 20) are error-free which indicates that subjects were concentrating on the primary task at the expense of the tapping task. However, the plot also shows that in a large number of trials subjects were complying with the tapping instructions and yet they made no errors on the primary task. In such error-free trials, complying with the random tapping instructions did not lead to poor performance on the matrix task. As can be seen in figure 6.3c, the scale for random spatial tapping is different from that of both the simple and regular tapping conditions. For random tapping, subjects in any trial are considered to be tapping reasonably to the criterion if the obtained MAD is between 10-20 whereas in the simple & regular tapping conditions, subjects are considered to be tapping reasonably to the criterion if the obtained MAD is smaller than 5. In addition, as can be seen in the above figures, the majority of the MADs fall within the boundaries of these rough criteria which indicates that there was an overall compliance with the tapping instructions in all of the 3 conditions.

Subjects' comments:

Since the VSSP is essentially a conscious process, then subjective reports can be of a special importance. Subsequent to testing, subjects were asked about their reactions to the task and the various conditions. In brief, the overwhelming majority of subjects (14 out of 16) rated the random spatial tapping condition as the hardest condition whilst 1 subject rated the control condition as the hardest and the last subject rated both the control and the random spatial tapping conditions as the hardest conditions. Regarding the easiest condition, 9 subjects rated the control condition as the easiest whilst the remainder of subjects (7) rated the simple tapping condition as the easiest condition. All subjects rated the regular spatial tapping condition as not too easy or not too hard but not the easiest or the hardest condition. In terms of the strategies used in processing the matrix task, 12 out of the 16 subjects indicated that they exclusively relied on visual imagery to process and retain the task material. The other 4 subjects reported occasional use of verbal memory in addition to visual memory. They reported some occasional use of verbal recoding of the task material (using words like: left, up) instead of relying on a mental image. Details and discussions of these comments will be provided in the discussion section. Appendix 5.5 shows examples of subjects' reports.

6.4. Discussion

The purpose of this final experiment in this project was to examine the effects of various movement tasks on maintenance of the 'simplified' variant of the Brooks Matrix task. In this variant, the TBR material were both presented and recalled visually. Unlike the standard Brooks task, this variant is assumed by the proposed process model to involve no redundant verbal processes and image generation mechanisms. There is no longer heavy CE involvement in the processing of the task and there is no longer crossing or recrossing of the A-L bridge. The information is now supposed to be encoded directly into the hypothetical visual buffer (VSSP) with minimum contamination by other processes. Hence, it was assumed that this variant will allow examining whether concurrent spatial movement interferes with visuo-spatial information because both share a common visuo-spatial WM resource or whether interference is merely due to the involvement of the hypothetical CE. Another aim of this experiment was to examine whether image maintenance involves a refresh mechanism comprising an 'inner scribe' writing information into an 'inner eye' as proposed by Reisberg & Logie (1993). It was predicted that if maintenance of visuo-spatial material is a function of a specialised visuo-spatial WM store involving an *inner scribe* feeding information into an *inner eye,* then a regular spatial tapping task should interfere with maintenance whilst adding a CE component, unpredictability, to this task should lead to greater interference. Carrying out a simple tapping task that involves no spatial or CE components was predicted not to interfere. Results showed that recall of visuo-spatial information was not affected by carrying out a regular spatial tapping task during a maintenance period but it was significantly interfered with by the same task when it was made unpredictable. A simple tapping task that involved no spatial or CE components led to no interference.

<u>Control vs automatic processing:</u>

As can be seen in table 6.a, the lowest number of errors was made at the control condition and slightly higher numbers of errors were made at both the simple and the regular spatial tapping conditions. Unlike these low error-rate conditions, random spatial tapping led to the highest number of errors. These results appear to match subjects' reports regarding the difficulty of the interference conditions. Most subjects rated the random spatial tapping condition as the hardest because it requires concentration and anticipation of the signals. Simple and regular spatial tapping conditions were rated to be much easier because they do not require concentration and they allow the subject to get into a 'mechanical' or a repetitive sequence. Using a different terminology, random tapping seems to be a controlled process whereas simple and regular tapping appear to be automatic processes. Schneider & Shiffrin (1977) proposed a motor learning theory called Automatic and Controlled Processing Theory which states that there are two modes of processing, controlled and automatic. Controlled processing seems to require conscious control, energy, and attention. It is also slow, serial, effortful, and limited by STM capacity. In addition, controlled processing is subject-regulated and is used to deal with novel or inconsistent information (e.g. the random signals in this experiment). Controlled processing, in general, is needed in situations where the required response varies from one trial or situation to the next, and is easily modified, suppressed, or ignored at the desire of the subject.

On the other hand, automatic processes do not require attention and they complete themselves without conscious control or mental effort by the subject. Schneider & Shiffrin's concept of automatisation, like that of Norman & Shallice (1986, see chapter 1), defines automatic processes as "unconscious" or without awareness. For instance, many people can walk over even ground whilst conducting a conversation or solving mental problems. Also, many aspects of driving a car and comprehending language appear to be automatic. Automatic processing appears to be fast, parallel, fairly effortless, unlimited by STM capacity and not under voluntary control. In general, automatic processing develops when subjects process stimuli in consistent fashion over many trials and it becomes difficult to suppress, modify, or ignore, once learned. Schneider & Shiffrin (1977) and Shiffrin & Schneider (1977) performed a series of studies contrasting controlled processing with automatic processing. They demonstrated that processes can become automatic with enough practice and once they do, devoting attention to them is no longer necessary and performance is no longer affected by the number of processes being performed simultaneously.

Automatisation was defined by Bahrick & Shelly (1958) as the gradual change from exteroceptive to proprioceptive control during prolonged practice of a repetitive task, although they admitted that no operations were known which could define the process. In fact, the criteria for automatisation are debatable (e.g. Cheng, 1985; Schneider & Shiffrin, 1985) but are often said (Annett, 1991) to include speed (being faster than controlled processes), relative uniformity of kinematic pattern, being involuntary, being relatively unavailable to introspective analysis, being free from interference by other concurrent tasks, and being independent of load as measured by stimulus or response information. In general, automatisation of performance is considered to be the last stage in the development of skill (Fitts, 1964). An experiment by Frith & Lang (1978) showed how predictability is a key element in automatisation of the performance of a task. They used a tracking task which had two components. In one component, movement of the target was essentially unpredictable whilst in the other, the movement of target was highly predictable. Frith & Lang concluded that improvements in performance were accomplished by subjects first building an internal representation of the more predictable component of the task which allowed performance to be more automatic. This permitted a greater proportion of attentional capacity, and hence more effort, to be put into coping with the less predictable component. This issue of predictability is relevant to the secondary tasks used in this experiment. Simple and regular spatial tapping were in response to highly predictable auditory signals whereas random spatial tapping was in response to highly unpredictable signals. Hence, unlike random spatial tapping, simple and regular spatial tapping could be considered as tasks that involve automatic processing.

The above account of the automatisation process by Frith & Lang relates to a distinction made by Poulton (1957) between two kinds of skill which he referred to as closed and open skills. Closed skills are those that can be carried out without reference to the environment whereas open skills are these which require adaptation of movements to events in the environment. Poulton mainly based this distinction on the notion of predictability within the environment. Closed skills referred to a highly predictable environment whilst open skills referred to an unstable, unpredictable environment. Within this view, random tapping could be regarded as an open skill whereas simple and regular tapping as closed skills.

A different and more traditional account of automaticity distinguishes between closed-loop and open-loop control (e.g. Reason, 1979; Pew, 1966; Annett, 1991). Closed-loop control relies on conscious attention whereas with open-loop control, attention or central-processing capacity is freed to allow mental activity independent of the current action. In a closed-loop task, such as compensatory tracking, the motor output is linked to and driven by an error feedback signal while in an open-loop task, such as striking a ball with a bat, the motor output is driven by a once-for-all pattern of signals, or motor program, that determines the form and magnitude of the response. An assumption of this account (Johnson, 1984) is that with practice, the learner will need to resort to the closed-loop mode of control less and less and, eventually, only at a few critical points. Pew (1966) suggested that as skill developed, there is a transition from strict closed-loop control to open-loop control with highly automatised action sequences and only occasional executive monitoring.

Hence, from the above discussion of controlled and automatic processing, it appears that the secondary tasks used in this experiment could be classified as either involving controlled processing (random tapping) or automatic processing (simple & regular tapping). Random tapping appears to be a controlled process that requires conscious control, energy and adaptation of movements to unstable events in the environment. This engagement of the central processing resources may have competed with image maintenance and hence led to the interference with maintenance of the Brooks visuo-spatial information. On the other hand, simple and regular tapping appear to involve automatic processing that requires no attention or mental effort and hence central processing capacity was freed to allow for efficient processing and maintenance of the visuo-spatial material. Thus, it appears that only the secondary task which involved controlled processing caused interference with maintenance of the matrix task.

As indicated above, subjects reported that the random tapping condition was the hardest and this indication matched the results of the experiment since more errors were committed at this condition. Subjects indicated that random tapping was the hardest condition because they had to 'think' about both the *spacing* of the 4 targets (the where) and the timing of the signals (the when) and that left little room for image rehearsal and maintenance. It was indicated that thinking about when the signals are coming disrupts the mental picture of the path. Regular spatial tapping, on the other hand, was reported to be less difficult than random tapping because it only required 'thinking' about the tapping targets (the where) whereas the signal was repetitive and predictable and thus allowed for image rehearsal whilst tapping. As one subject put it, *"regular tapping was routine and you know where you are going so you could try and 'see' the picture in your mind whilst tapping"*. However, regular spatial tapping was still indicated by subjects as being not too easy since, as one subject put it *"you still have to think about both the movement of your hand (tapping) as well as the movement in your head (the path)"*.

In addition, unexpectedly, about 7 subjects reported that the no interference condition was not the easiest condition. They indicated that thinking too much about the image during the 30 seconds unfilled maintenance interval causes confusion. Thinking about exactly which squares the path has gone through was more difficult than just thinking of it as an overall shape. So as one subject put it *"the crucial element to correct recall is not to think too much about it once encoded"*. Those subjects indicated that the simple tapping condition was easier because *tapping 1 target was easy and it provided something to do which kept them from thinking or reading too much into the image and kept their minds from wondering around*. Simple tapping, as these subjects report, is repetitive and thus it leaves enough room for remembering the image. Within the context of controlled and automatic processing, it seems that these subjects tend to resort to controlled processing of the image during the no interference interval whereas simple tapping tends to keep them from this controlled processing and makes them rely instead on automatic processing of the image. In this case, controlled processing of the image is counterproductive since it heavily engages the CE in image maintenance. As previously mentioned, controlled processing involves conscious control, energy and attention whereas automatic processing requires minimum conscious control or mental effort by the subject. Hence, at least from the subjective reports of these cases, paying too much attention to the image or overprocessing it during maintenance appears to be counterproductive whereas passively maintaining it in the visual buffer whilst repetitively tapping a single target seems to be more efficient.

In terms of the strategy used in processing the matrix task, the majority of subjects (12 out of 16) reported a complete reliance on their visual imagery to process the task. They indicated that they relied on creating a picture or an image of the path which is often described as a pattern (a shape, a line of shaded blocks, a zigzag, a snake-like line etc.) rather than a full picture of the matrix. This image is also often described as an overall pattern rather than a detailed description of which individual squares the path had crossed. Such an image is then used as a mnemonic at retrieval. The other 4 subjects, on the other hand, reported that in addition to the visual image, they occasionally used their verbal memory. They indicated occasions in which there was verbal recoding of the movements of the path (i.e. verbalising directions such as left, down etc.). These 4 subjects indicated that this verbal recoding occurred only in the two easiest conditions (control or simple tapping). In the other two conditions, they reported a complete reliance on their visual memory and pointed out that in those two conditions, particularly in the random tapping condition, it was very difficult to keep words in their *minds* whilst randomly tapping. In terms of the WM model, in these 4 cases there is occasional involvement of the AL in performance of the matrix task but only in the control or simple tapping conditions whereas the regular and random tapping appears to force subjects to rely exclusively on the VSSP in processing the matrix task. This occasional verbal re-encoding of the nonverbal material is not unexpected since there is evidence (Holding, 1994) that human information-processing preferentially re-encodes material from other modalities into a verbal form that in turn can engage the AL. For instance, Conrad (1964) found that even visual letters gave rise to confusions that were acoustic in nature.

In regard to error rate, it appears that a low error rate occurred in this experiment in comparison to the error rate obtained in Experiment III, Condition 4, in which the 'shortened' matrix task was also presented and recalled visually. In Experiment III, Condition 4, the mean percentage of error was 5.95 whereas in this experiment it was only 1.81 in the control condition. This is an unexpected result since in Experiment III, Condition 4, recall was immediate whereas in this experiment it was after an interval. The expectation was that after an interval, recall will either deteriorate or at least not show an improvement over immediate recall. However, the opposite pattern occurred in which recall after a maintenance interval was better than immediate recall. The interpretation of this result is unclear but it could be that the maintenance interval provided an opportunity for a consolidation process of the image in which the information gets encoded into a LTM store. Such a process is not possible with immediate recall of the information. Some subjects in their reports indicated that the maintenance interval allowed time to *check* the image and correct mistakes. However, it should be noted that in this experiment a different sample of subjects was used in addition to the fact that the sample in Experiment III, Condition 4, consisted only of 8 subjects whilst in this experiment 16 subjects were tested.

The SP curve:

In regard to the SP analysis, the obtained curve appears to match the reports of subjects. All subjects indicated that the end of the path was harder to recall than its beginning. The SP curve showed that the highest error rates were at the last two positions. The reasons for this result are not so clear but as some subjects indicated that more attention and concentration are paid to the beginning of the path. It was indicated that the beginning of the path gets scanned or rehearsed more than the end. Some subjects pointed out that during image maintenance, the last two movements of the path are more prone to fading. Another reason could be related to the VSSP having a limited capacity. It thus seems that every item encoded occupies a space in the VSSP until space or span runs out for the last item. This is highlighted by the indication made by some subjects that *"by the end of the path there are loads of information to think about"*. Another reason for not obtaining a classical SP curve (having both primary & recency effects) could be related to the nature of the TBR material. The materials were presented in a serial and spatial sequence (order) and were recalled in the same sequence. In other words, the task demanded serial-recall rather than free-recall which is associated with the classical SP curves.

Tapping data:

In regard to the analysis of the secondary task data, the results showed an overall pattern of compliance with the tapping instructions. In all of the tapping conditions, most subjects were complying reasonably with the instructions to tap in time with the auditory signal. In some cases, however, the tapping data under some conditions did not match the criterion. Such cases are expected since in dual task conditions, mutual interference is expected. That is, in dual-task paradigms if the two concurrent tasks share a common cognitive resource, then inefficient performance on both tasks will occur. Also, generally in dual-task paradigms small decrements in performance are expected since the process of coordinating, organising, and allocating resources may require resources in its self. This is commonly referred to as cost of concurrence (e.g. Wickens, 1984) and this issue has been discussed in Experiment 2-a. Although in this experiment the primary and secondary tasks were not performed concurrently at encoding, it is still considered as a dual-task experiment since the secondary task was performed whilst the primary task was being retained. In general, the tapping data showed that there was less compliance with the tapping instructions in the random tapping condition in comparison to the other two tapping conditions. The reason for this could be due to the difficulty of random tapping or the fact that both maintenance of the visuo-spatial information and random tapping shared and competed for a common WM resource and in this case it is the CE. In the simple and regular spatial tapping conditions, there was more compliance with the tapping instructions and this result could be taken as an indication that simple and regular tapping required resources that are different from the resources required for maintenance of the matrix task.

VVIQ

Finally, regarding the correlation of the overall performance on the matrix task with subjects' ratings on the VVIQ, the results showed a significant positive correlation. This result is in contrast to the results obtained in Experiment III in which performance on the matrix task did not significantly correlate with ratings on the VVIQ. However, it should be noted that Experiment III involved very small samples (8 subjects in each condition) which make the results suspicious. In addition, Condition 4 of Experiment III is the only condition which resembles the current experiment in terms of the modalities of encoding and decoding being both visual. The other three conditions involved different manipulations in the modalities of input and output of the 'shortened' variant of the Brooks Matrix. The obtained significant positive correlation between ratings on the VVIQ and performance on the current variant of the Brooks task is also in contrast to the result obtained with the VMIQ in Experiment II which, as did this experiment, involved a movement interference paradigm. In Experiment II ratings on the

VMIQ failed to correlate with performance on the Brooks task when it was presented verbally or visually. Therefore, it was suggested that the VVIQ be used instead of the VMIQ especially that it has been indicated (e.g. Logie & Marchetti, 1991; Logie, 1995; Quinn, 1991) that once encoded, the matrix visuo-spatial information is retained as a static visual pattern in a passive visual imagery or WM store. Hence, if the Brooks Matrix relies on pure *visual* imagery for its maintenance, then a more specific measure of *visual* imagery may be more appropriate to predict performance on the Brooks than the VMIQ which is specifically concerned with visual imagery of movement and the imagery of kinesthetic sensations associated with movement.

The VVIQ (see chapter 2) is one such measure of visual imagery which consists of only visual items that refer to common situations and scenes and the subject's task is to rate the vividness of the visual imagery that the items evoke. If the obtained significant correlation is taken as a valid result and if we assume that the VVIQ is a valid and accurate measure of visual imagery, then this result could be taken as supporting the indication by Logie (1995) and Quinn (1991) that maintenance of the matrix task is indeed the function of a passive visual WM store. The VVIQ is indicated by Marks (1972) to be a valid discriminator of subjects with good and poor visualising ability. The obtained significant correlation between vividness ratings of visual images and retention of a path within a matrix may indicate that both are mediated by the same covert event - a visual image. However, these inconsistent results must be treated with caution and a thorough discussion of the relationship between subjective reports of imagery vividness and performance on visuo-spatial memory tasks was provided in the last section of chapter 5.

<u>Summary:</u>

This experiment examined the effects of various movement tasks on maintenance of the 'purified' variant of the Brooks Matrix task. The results showed that only the random spatial tapping task, that have both spatial and CE components, interfered with maintenance whereas the regular spatial tapping task led to no interference. The prediction was that both tasks should interfere with the random task leading to greater interference. This prediction was based on the assumption that maintenance of visuo-spatial material involves a rehearsal loop comprising an 'inner scribe' writing information to an 'inner eye'. If the VSSP is like a board over which visuo-spatial information is registered then carrying out a spatial 'suppression' task should overwrite the visuo-spatial representation. Also, if the VSSP involves an active *inner scribe* that refreshes the representation, then adding a CE element to the spatial tapping task should lead to further interference. Results showed that only the task that presumably loads the CE led to interference. In other words, the visuo-spatial WM hypothesis which states that maintenance of the matrix visuo-spatial information is a function of a specialised spatial WM resource was rejected since a presumably spatial suppression task did not disrupt performance. On the other hand, the CE hypothesis which states that general purpose resources are responsible for maintenance of the matrix visuo-spatial information, was supported since the regular tapping task did not interfere but the random tapping task interfered presumably because of its assumed additional executive loading. The result of spatial movement not disrupting image maintenance may be taken as indicating a dissociation of visual imagery from the motor output system.

As can be seen in figure 6.1, the results were clear in showing no effect of regular spatial tapping but a substantial effect of random tapping. These data point to the idea that maintenance of the matrix visuo-spatial material does not appear to rely on any form of spatial temporary storage. These data also indicate that maintenance of the matrix task relies on CE resources and this highlights the importance of the CE in imagery. An alternative view would suggest that maintenance of the matrix task is a function of a passive visual WM store that works in conjunction with the CE as will be discussed in the next section.

6.5. General discussion

In general, it has been shown in this research that a spatial movement task interfered with encoding of the Brooks Matrix task when it was either encoded verbally or visually (Experiment II) but the same movement task did not interfere with maintenance of the 'simplified' Brooks task (Experiment IV). This isolates the encoding stage rather than the maintenance stage as the locus of interference. This spatial task interfered with visual and verbal encoding of the Brooks task in Experiment II. Visual, as opposed to verbal, encoding is assumed by the process model to involve no heavy CE loading since the task materials are supposed to be encoded directly into the visual buffer with no redundant verbal and image generation processes involved. Hence, it would be reasonable to conclude that the interference by the spatial task is not due to CE loading but rather to the fact that encoding of the matrix task and carrying out the spatial task competed for the same spatial WM resource. In addition, it has been shown that a CE task (rhythmic tapping) interfered with the encoding of the Brooks Matrix whether it was verbal or visual (Experiment II), and also another CE task (random tapping) interfered with maintenance of the 'simplified' variant of the Brooks task (Experiment IV). These CE tasks still interfered with the encoding and maintenance of the Brooks Matrix variants despite the fact that the task has been simplified in such a way that it no longer involves any verbal components and thus no crossing or recrossing of the A-L bridge to generate images from verbal statements or vice versa. A Simple tapping task led to no interference at encoding or maintenance and this lack of an effect by this task suggests that any effect by the spatial and CE tapping tasks, is not simply due to generating a repeated motor response (Logie & Salway, 1990). The following section will attempt to provide an account of these results and their implications for the structure of WM.

a) Regarding the first result that the effect of the spatial movement task was confined to the active encoding, rather than the retention, stage, it appears that this result replicates previous findings in the literature (e.g. Morris, 1987; Quinn, 1988a, 1991). In such studies, various movement tasks were found to disrupt performance but only if movement occurs during encoding of the primary visuo-spatial task rather than during a maintenance interval. Morris cited the disruption of attention as the most obvious explanation and concluded that executive control was required at encoding but not during maintenance rehearsal because secondary tasks that placed a load on the CE only produced performance decrements during encoding. Morris suggested that the VSSP cannot operate independently of the CE, at least during encoding and retrieval operations. Quinn (1988a) interpreted his results as suggesting that after the encoding phase, the form of the representation within the VSSP may be sufficiently different to preclude any interference. The spatial code may be heavily involved only during actual processing of information whether at encoding or retrieval whilst during maintenance, the processes used may be of a different nature. Another interpretation put forward by Quinn was that during maintenance, the CE involvement is lessened. Since some of the interference effects have their locus in the CE, it appears that whenever the dependency of the VSSP on the CE is reduced, interference is also reduced. Quinn (1991) found movement interference only during active encoding rather than during maintenance of the Brooks Matrix. Quinn offered an interpretation suggesting that once formed, the Brooks directions are retained as an overall pattern rather than as a sequence of discrete relative directions and thus secondary discrete movement does not interfere. If this is true, Quinn argues, then an interference task could be designed which would selectively interfere with a static complex pattern rather than with spatially defined sequences and so gain a better insight into the form of the representation.

Logie & Marchetti (1991) pointed out that the findings that secondary spatial movement interferes with the VSSP at encoding whilst the VSSP seems impervious to interference while material is being maintained, suggest that whatever cognitive mechanisms are involved in encoding are also involved in the control of active movement. Also, they suggest that the system responsible for *retaining* the encoded information is not associated with movement control. Within the context of WM, these findings are suggested by Logie & Marchetti to be anomalous since it is assumed that the VSSP would be involved in temporary *maintenance* of visuo-spatial information. If there is a specialised WM resource for dealing with spatial material, this resource should also be involved in retention of such material. Concurrent movement should, thus, disrupt both encoding and maintenance of visuo-spatial material if the same system is involved in each case. One possibility, suggested by Logie & Marchetti to account for these findings, is to assume that the VSSP comprises two separate WM systems, one visual and one spatial and both operating more or less independently of the CE. Hence, the *spatial* system is involved in encoding of the visuo-spatial tasks that were used in the above studies whereas the *visual* system is involved in the maintenance of such tasks. Logie & Marchetti indicated that in tasks such as the Brooks Matrix, only the initial encoding of information needs to be a spatial process. Encoding the positions of particular digits in a square matrix would qualify as a spatial process by most criteria. Once encoded, however, the subject needs only to maintain a static pattern of digits in an imaged matrix and this pattern will not be susceptible to movement interference. Thus, as suggested by Logie (1989), Logie & Marchetti proposed that the VSSP may comprise two functions, a passive visual store and an active rehearsal process. The visual store is involved in retention of pure visual information and patterns whilst the active rehearsal process is related to the control of movement.

Recently, Quinn (1994), when discussing some of the above studies, argued that the finding that the VSSP is impervious to movement interference while information is being maintained is a puzzling result since maintenance of information is presumed to require active monitoring. In attempting to clarify this puzzling finding, Quinn pointed out that several distinctions can be drawn between encoding or retrieval of information and maintenance of already encoded information. For instance, once encoded, the discrete elements could be held as a unified pattern and so will not be susceptible to the type of interference that occurs during the encoding or retrieval of the component parts. It is only during these encoding and retrieval operations that discrete movement from location to location takes place. Therefore, Quinn suggested that memory for patterns may be different from memory for locations and he cited evidence provided by Smyth & Pendleton (1989) that memory for movement configurations involves different processes from those involved in movement to locations. Movement configurations, in which location is relatively unimportant, may be cognitively similar to memory for patterns in which the component parts do not need to be kept under cognitive scrutiny as long as they can be retrieved when required using inferential processes.

The above indications and interpretations regarding why spatial movement does not disrupt maintenance of visuo-spatial tasks such as the Brooks Matrix seem to be supported by the reports provided by subjects in this experiment regarding the form of the mental representation which they used in processing and retaining the current variant of the matrix task (see Appendix 5.5). Subjects mostly indicated that their image was in the form of a pattern, a shape or a line in which the bends indicate changes in direction rather than a complete matrix with the items (crosses) placed in their designated cells. Some subjects indicated that thinking of which individual square the path crossed each time was more difficult than just remembering the path as a line or a pattern. As one subject put it *'I concentrated not on the x but on the pattern of squares and what shape they will make'*. Hence, from the above discussion, it appears that the most plausible explanation for the first result in this experiment, in which regular spatial tapping did not interfere with maintenance of the matrix task, would be that a passive visual WM store was involved in maintenance of such information. And as suggested by Quinn (1991) it would be interesting to design an interference task that would selectively interfere with a static pattern and not with a spatially defined sequence and thus gain some insight into the form of the representation.

A recent study by Toms et al (1994) attempted to examine this issue by exploring whether irrelevant visual input is disruptive to storage of imaginal information in a primarily spatial task- the Brooks Matrix task. It was indicated that recent discussions of visuo-spatial WM have suggested that this subsystem may incorporate a visual buffer which holds visuo-spatial information relatively passively. These recent discussions of the nature of the VSSP have indicated the possibility of two separable mechanisms (e.g. Baddeley, 1990; Logie, 1989; Logie & Baddeley, 1990). In addition, evidence has been provided (Farah et al, 1988) that spatial and visual dimensions of imagery can be dissociated, suggesting that representation of visual appearance and of spatial location are handled by functionally independent subsystems. Farah et al pointed out that the 'imagery' tasks used within cognitive experimentation differ in their demands upon these subsystems. Thus, a task which asks subjects to indicate whether a particular animal has a long tail (Kosslyn, 1975) would be predominantly visual in nature whilst a mental rotation task (Cooper & Shepard, 1973) would be predominantly spatial. Hence, the susceptibility of any given task to visual or spatial interference would vary according to the demands imposed by such a task upon the visual and spatial subsystems. Toms et al indicated that although the VSSP might be conceptualised as two separable subsystems, spatial and visual scratchpads, the potential functional separablity of such subsystems does not necessarily entail their functional independence in normal subjects carrying out visuo-spatial tasks. Although tasks may be classified in terms of their relative spatial or visual demands, many imagery-based tasks are both spatial and visual in nature.

In short, Toms et al indicated that empirical investigations of visual interference with information held within the VSSP have yielded rather equivocal results. Hence, they attempted to examine the characteristics of the putative visual store in more detail by examining the effects of exposure to irrelevant visual material during encoding and during maintenance of the Brooks task. Their results showed that irrelevant visual material has obligatory access to a specialised visual store by interfering with storage of the Brooks visuo-spatial material in WM. The irrelevant visual material disrupted the Brooks Matrix task to the same degree during passive maintenance as during encoding. In this regard, it is interesting to note that, using the same Brooks Matrix task or variants on this task, Quinn (1988a, 1991) and the current study have shown that spatial movement tasks disrupted performance of the matrix task only during encoding rather than during maintenance. This might suggest a dissociation between the effects of spatial movement and the effects of visual interference, consistent with the notion that spatial movements interfere with active spatial processing at encoding (and retrieval, Morris, 1987) whereas visual input interferes with stored material, even when that material is not being actively processed. In other studies where interference by spatial movement during a maintenance interval was reported (e.g. Smyth & Pelky, 1992; Logie & Marchetti, 1991) the primary task also required preservation of order information that may have involved a rather more active rehearsal strategy during the interval than that required by tasks such as the Brooks task or Morris's (1987) task where maintenance of pattern information only was necessary.

Therefore, in terms of the visual vs spatial debate, it appears that the VSSP may comprise at least two mechanisms, visual and spatial. Logie (1995) indicated that many of the above data could readily be accounted for if we were to assume a VSSP with two mechanisms. A spatial mechanism may be involved during encoding and retrieval of spatial positions whilst a visual temporary mechanism could be responsible for retaining the image pattern of, for instance, digits in specific locations in a matrix. Hence, Logie suggested that in the above tasks we can envisage an essentially spatial process of imagined movement during encoding, but something more like a static visual image being used during maintenance. Recall may also be a spatial process if we assume that the visual image is mentally scanned in order to report the retained pattern.

b) In the second major result in this study, a CE task (rhythmic tapping) interfered with both verbal and visual *encoding* of the matrix task (Experiment II) and another CE task (random tapping) interfered with *maintenance* of the 'simplified' variant of the matrix task (Experiment IV). In regard to the CE task's interference during *encoding* despite the fact that CE involvement in the Brooks Matrix was reduced by changing the modality of encoding from verbal into visual, it seems that this result supports previous conclusions in the literature. For instance, Morris (1986b, 1987) proposed that the CE is 'coupled' to the VSSP during active encoding of spatial material and that this coupling is broken during maintenance rehearsal to liberate executive resources for other tasks after such encoding. Toms et al (1994) argued that the VSSP may comprise two functions, a spatial function and a visual function, with the spatial function, perhaps ensconced with the CE complex, operating upon the passive visual store and thus spatially manipulating the material contained therein. Baddeley (1993) indicated that all WM tasks draw at least minimally on the CE. Logie (1995) argued that spatial encoding may not only be spatial but also effortful. According to Logie, encoding appears to use general purpose resources instead of or in addition to specialised spatial processing.

As indicated above, the CE task (random spatial tapping) interfered with *maintenance* of the 'simplified' matrix variant whilst a regular spatial tapping task that has no CE component did not interfere. This latter result was interpreted above as suggesting that the matrix information is held in a passive visual WM store which is not susceptible to movement interference. However, if the information is held in such a passive visual store, why should the CE task be so disruptive? The following are some speculative attempts to answer this question:

First, it has been suggested in the literature (e.g. Smyth & Scholey, 1994a) that maintenance of visuo-spatial information is active and is similar in some ways to active looking. Smyth & Scholey indicated that visuo-spatial WM requires the active maintenance of visuo-spatial information and is interfered with by tasks that require shifts of spatial attention. In addition, Farah (1989) proposed that visual imagery is like visual attention, whilst Kosslyn (1991, Kosslyn et al, 1990) suggested that maintaining a visual image requires effort. These indications could be taken as implicating the CE or a component of the CE (e.g. a visual or spatial monitoring device) to be involved in image maintenance. If this is the case, then it is not surprising that a CE interpolated task led to interference with maintenance of the matrix path.

Second, if we assume that the hypothetical passive visual WM store is equivalent to Kosslyn's (1980, 1991) visual buffer then it is not surprising that a CE loading task interfered with image maintenance. In his imagery model, Kosslyn described the concept of a visual buffer which acted as host for the consciously experienced image. The buffer was assumed to place limitations on the resolution of the image it contained, and to have a foveal-like area that is of a higher resolution and that is linked to the area of attentional focus. A number of processes was proposed to operate on the contents of the buffer. Some of which are: Scan, where the focus of attention shifts to another part of the image; Pan & Zoom which are similar to 'viewing the image' respectively from further away to take in more of the periphery, or from close up to examine detail; and Rotate which allows manipulating the orientation of the object or the scene depicted in the image. Also, there are the functions of Generate & Regenerate that allowed initial forming of the image, and refreshing the image or redrawing it in a different form to exclude information or include new information. Kosslyn (1991) indicated that the visual buffer, which he equates with visual STM, corresponds to the *array* in the original theory (Kosslyn, 1980) and he modified his original view of the visual buffer as a static structure, exactly analogous to an array in a computer, into a more *active* visual buffer that itself performs much computation. In addition, Kosslyn pointed out that images fade quickly and require effort to maintain and the more perceptual units that are included in an image, the more difficult it is to maintain.

According to Kosslyn, image maintenance can be regarded as a special case of image generation, with the generation mechanisms simply being used repeatedly to refresh an existing pattern of activation in the visual buffer. Logie (1995) pointed out that the CE has been widely implicated to be responsible for imagery generation and manipulation and an overlap between Kosslyn's concept of the visual buffer and the concept of WM would be to suggest that the CE hosts the visual buffer and controls the operations that act on its contents. According to Logie, Kosslyn's visual buffer contains the conscious image which includes the visual properties of the image and the information about the relative location of objects to one another plus any semantic information associated with the image. Hence, it is more like a workspace for visual imagery than a buffer as such. The visual WM store provides a kind of a cache memory for information which may be readily brought into the conscious image for manipulation and inspection. In other words, the visual cache contains more visual information than does the conscious image, and information is exchanged between the respective systems. Hence, unlike Kosslyn who equates the visual buffer with visual STM, Logie regards the visual WM store as a back-up store on which the conscious visual image (the contents of Kosslyn's visual buffer) relies. In addition, Logie indicates that Kosslyn's processes that act on the contents of the buffer such as Scan, Generate, Regenerate etc. could be regarded as procedures activated from LTM and available to the CE along with a wide range of other algorithms and heuristics for processing information. The Generate/Regenerate functions provide a means to rehearse and refresh the contents of the buffer. The Generate/Regenerate processes are characterised by being sequential with the various parts of the image generated in a particular order and an emergent property of such a sequential process is that it could retain movement sequences. The visual cache provides temporary storage of information as required, and *generating* and *regenerating* an image provides a rehearsal function that refreshes the contents of the visual cache as well as the visual buffer. An emergent property of this rehearsal function, according to Logie, is that it can represent movement.

A **third** consideration of the result that a CE task interfered with maintenance of the matrix task would be in terms of a refresh mechanism proposed by Reisberg & Logie (1993). They proposed a refresh mechanism for the VSSP which parallels that of the AL. Verbal material is maintained through an AL in which an inner voice (active articulatory rehearsal process) repeats or articulates the verbal material and so refreshes the contents of the inner ear (passive auditory store). Visuo-spatial material is conceptualised by Reisberg & Logie as being maintained by a parallel mechanism in which an inner scribe (active rehearsal process) rewrites material and thus refreshes the contents of an inner eye (passive visual store). The active rehearsal process (inner scribe) is indicated by Logie (1989) to be related to the control of movement and to be akin to some form of mental scanning of the visual representation.

This final experiment attempted to test this proposal of a refresh mechanism. It was assumed that during a relatively long maintenance interval of the matrix task, the visuo-spatial representation in the visual store will be prone to decay and thus the rehearsal mechanism (inner scribe) will be needed to refresh the contents of this store. The existence of such a rehearsal mechanism was thus tested by asking subjects to carry out some interpolated secondary tasks that were designed to examine some of the assumptions on which the concept of the refresh mechanism was based. Results did not entirely support the existence of such a rehearsal loop. First, the regular spatial tapping task did not interfere with maintenance whilst it was supposed to interfere if the 'inner scribe', as suggested by Logie (1989) and Reisberg & Logie (1993), is related to movement control and motor planing. The only source of interference was from a tapping task that presumably loads the CE. This indicates that whatever rehearsal mechanism is involved in refreshing the visuo-spatial representation, it is most likely to be associated with CE resources rather than with a spatial or movement-based mechanism. In general, the CE task was supposed to interfere since the hypothetical inner scribe is assumed to involve an *active* rehearsal process that should involve CE resources. The question now is how and where was the image of the path maintained during the 30 seconds filled or unfilled intervals? Before attempting to answer this question, the following are summaries of some of subjects' replies to this question:

-The image was a picture of a line of blocks. I tended to forget it for couple of seconds but then I go back to it to make sure it is still there.
-It is a shape that I stamp in the back of my mind and then bring back at recall.
-I was thinking of the path whilst tapping. With random tapping there was no room to try to refresh the picture and if I did I made tapping mistakes. But with regular tapping there was a room to try to 'see' the picture in your mind whilst tapping. During the empty interval, I was rehearsing the picture in my head.
-Random tapping requires concentration so it kept my mind drifting from the image and the image shifts to the back of my mind. Otherwise, I was able to pay more attention to the image.
-During the interval there was a shape in my mind and random tapping made it harder to keep the image in my mind but in the other conditions I could tap and rehears the image by trying to 'see' it in my mind.
-It was a line in my head that I tended to put aside whilst randomly tapping and I found that I could mostly bring it back.
-During the two spatial tapping conditions, I didn't keep the image *'in front of me'* because I had to visualise the 4 tapping targets. So I kept the image *up there* whilst tapping. If I did them both at encoding it would jeopardise the image of the path.
-It was a line like the one I draw and random tapping made me unsure of it since it distracted me from scanning or *thinking of* the image. During tapping, I was thinking of two things, the image and the tapping. So I just didn't put the image aside and that is why I had problems with random tapping because I sometimes had to leave the image and concentrate on the tapping.
-It was like a pattern which was still up there whilst tapping and it doesn't fade even with random tapping.
- It was like a line or a shape and every now and then during tapping I went back to check it and this rehearsing was mainly disrupted by random tapping.

Thus, from the above discussion and the above comments by subjects, it appears that during the maintenance interval the matrix visuo-spatial information was mostly held as a pattern or a shape in a passive visual imagery store that also requires CE resources for its operations but that is not related to the control of movement. This visual buffer, as indicated by Kosslyn (1991) and Logie (1995), appears to be hosted by the CE. The result of random tapping interfering with image maintenance highlights the importance of the CE in image maintenance. The result also supports the above indications by Kosslyn and others that images fade quickly and require effort to maintain. Furthermore, this result highlights the importance of the CE not only during encoding of tasks like the Brooks Matrix but also during maintenance of such tasks. This result, hence, does not support the indication by Logie & Marchetti that "the CE is involved in encoding the Brooks Matrix material in some form of mental image, but is less important for maintenance of the information in that image, or the image itself" (1991, P.113); and also the indication by Logie (1995) that the visual WM system is a subsidiary system that requires little in the way of CE or general purpose resources to provide a temporary storage function.

In summary then, a spatial tapping task that has been used in the literature (e.g. Farmer et al, 1986) as a spatial suppression task, did not prevent the rehearsal system from operating during maintenance of the matrix visuo-spatial information whilst a CE loading task interfered with the rehearsal process. In terms of the analogy between the AL and the VSSP, both systems appear to comprise passive perceptual input stores and in both cases, the problem of coping with rapid decay from the store is solved by an active control process (Baddeley 1986, 1990; Logie, 1989, 1995; Reisberg & Logie, 1993; Toms et al, 1994). However, the rehearsal loop or mechanism in the VSSP does not appear to be identical to that of the AL. The hypothetical *inner scribe* does not seem to rewrite material to the *inner eye* in almost the same way that the *inner voice* recirculates or articulates material to the *inner ear*. Annett (1995) indicates that the problem which immediately comes to mind is that whilst the 'inner voice' may generate inputs that are very similar to the original stimulus, the 'inner scribe' may not be able to generate all the features of the original material using a single motor resource since painting pictures is a process that is different from the process of repeating words. The finding that interference by concurrent movement tasks, such as tracking and tapping on spatially distributed targets, is confined to the encoding phase when the TBR items are being presented rather than the retention phase, implies that concurrent movement does not disrupt the 'refresh' mechanism of the VSSP in quite the same way that a concurrent verbal task appears to disrupt the AL.

Toms et al (1994) discussed the result that spatial tapping or tracking has a selective interference effect confined to tasks with a spatial component that are unlikely to require any representation in the passive visual store but require the monitoring of several locations (as in the Morris, 1989 paradigm). They argued that this result indicates that if a passive visual store exists, it does not engage in spatial processing and it is more likely that a spatial processing device, perhaps ensconced with the CE complex, operates upon the passive store and spatially manipulates the material contained therein. Toms et al indicated that if this interpretation is accepted, then the validity of comparing articulatory suppression to spatial tapping or tracking is in doubt. A simple interpretation of articulatory suppression have been suggested by Reisberg et al (1984) in which they argued that if a subject is engaged in such suppression then they cannot use their voice apparatus to repeat, and thus maintain, items by whispering them. However, there is no evidence that subjects store accurate visuo-spatial representations on their fingers by configuring their hand posture into a representation of the TBR shape. Spatial tapping or tracking would prevent this, but it does more than this, and critically one would not expect it to gain access to a passive visual store. On the other hand, articulated words are assumed (Baddeley, 1990) to be translated into phonological representations and thus enter the passive phonological store.

The above discussion and indications regarding the proposed refresh mechanism appear to lend support to the indication by Annett (1995) that the analogy between the refresh mechanism of the AL and the VSSP has only rather indirect support and some serious theoretical difficulties. One of which is that phonological coding is time-dependent in a way in which visuo-spatial coding is not, and this point was elaborated in the introduction to this experiment. Annett pointed out that the AL seems to be a necessity for phonological coding but a parallel visuo-motor loop may not be for retaining visuo-spatial material. An action-perception feedback loop would, according to Annett, be advantageous to maintaining visuo-spatial information in WM only in regard to information that is needed to interpret and imitate the perceived actions of others since it is only this kind of visuo-spatial information that requires the encoding of time-dependent information.

Hence, in regard to the question of whether image maintenance involves a refresh mechanism comprising an 'inner scribe' writing information to an 'inner eye', the results of this experiment did not support the hypotheses of the experiment. Regular spatial tapping did not prevent the hypothetical rehearsal loop from operating which indicates that such rehearsal mechanism is not related to movement control. If it can be assumed that the visuo-spatial store subserving the visuo-spatial information in WM does not require continuous rehearsal- perhaps needing only an intermittent check on spatial parameters- as suggested by Holding (1994), then interpolating the regular spatial movement task should cause little disruption. This view of maintenance in the VSSP is in contrast to the view of maintenance in the AL which clearly demands active and continuous processing and recirculation of the TBR verbal material. Only random spatial tapping interfered with the operation of the hypothetical refresh mechanism. Thus, it was concluded that the visuo-spatial image was most likely maintained in a 'visual' WM store that requires CE resources for its operations but this store does not seem to be maintained by a rehearsal loop involving an 'inner scribe' that is related to movement planning and control.

To conclude this discussion, the following is a brief discussion of the issue of a refresh mechanism for the VSSP within a modified view of WM presented by Logie (1995). Logie indicated that the suggestion by Logie (1989) that the VSSP comprises two functions, a passive visual store and an active rehearsal process related to movement control, has a highly seductive symmetry with the AL and in this respect the model of the AL as a framework for the VSSP has proved to be fruitful although he urged some caution in taking the analogy too far. Logie used his proposal to interpret the result obtained by Logie & Marchetti (1991) in which a double dissociation was demonstrated between the effects of visual and spatial tasks. He suggested that retention of colour hues was the responsibility of the passive visual store and that is why irrelevant visual input, but not spatial movement, caused disruption of its contents during a retention interval. Retention of a series of movements, on the other hand, was the responsibility of the rehearsal mechanism and that is why irrelevant secondary movements, but not irrelevant pictures, disrupted recall of the original series of movements. In this case it could be inferred from Logie's interpretation that the passive visual store is self-contained. That is, it has its own maintenance rehearsal mechanism since if the active rehearsal process (inner scribe), is involved in maintaining the contents of the visual store, then the secondary movement task should have interfered with retention of the colour hues because the *inner scribe* is assumed to be related to movement control. This did not occur in the Logie & Marchetti study. Moreover, Logie indicated that the visual temporary store is a passive store that is subject to decay and to interference from new information coming in. And that the spatial mechanism (inner scribe) is a system that is related to movement planing and control and is also used to rehearse the contents of this visual store. Logie did not explain how this mechanism could possibly refresh the contents of the visual store (e.g. colour hues) without being susceptible to interference by concurrent spatial movement! It could be understood from the above indications by Logie that the spatial mechanism (inner scribe) is the only mechanism which is responsible for refreshing the contents of the passive visual store. In this case spatial movement should interfere with maintenance of the information in the visual store even if this information is purely visual. This did not occur in studies such as that of Logie & Marchetti and that result could even be taken as unsupportive of a rehearsal mechanism (loop) in the VSSP in the form presented by Logie which involves an active spatial mechanism refreshing the content of a passive visual store.

Chapter 7

Conclusion, Positions and Directions

7.1. Overview:

The preceding six chapters presented details of this experimental study which attempted to tackle the issue of movement interference in visuo-spatial WM. The first two chapters provided a comprehensive review of the literature starting off with a historical background and evidence that supported the existence of a memory function that deals with information solely on a temporary basis. Then evidence was briefly reviewed that supported the existence of a visuo-spatial WM subsystem which is assumed to be responsible for temporary processing and manipulation of visuo-spatial information and images, and which is also linked to the planning and control of movement to targets in space. Some issues and debates regarding the characteristics of this proposed WM subsystem were then considered including the debate concerning the role of movement in this WM subsystem and whether concurrent movement interferes with visuo-spatial processing because both tasks share a common 'motoric' WM component or whether interference is due to involvement of the hypothetical CE. The subsequent chapters then described a series of experiments that attempted to systematically examine this issue and presented some conclusions drawn from these experiments. This final chapter has three objectives. First, to draw overall conclusions from the present study; second, to attempt to position these conclusions within the current literature on visuo-spatial WM and motor imagery; and finally an attempt will be made to briefly discuss the implications of research in this area to applied settings, and to suggest possible directions for future research.

7.2. Conclusion from the present study

This research program stemmed from current debates regarding the nature of visuo-spatial WM (the VSSP) and specifically the role of movement in this proposed STM component. As discussed in chapter 2, movement has been shown to interfere with concurrent visuo-spatial processing, with the interference being marked during the encoding and possibly the retrieval operations rather than during maintenance of information in WM. The basic research question was why movement should be so disruptive; Is it because both the primary and the secondary tasks require a common resource within WM? If so, what is the nature of that resource? Is it a representation of space or is it perhaps the involvement of the hypothetical CE? Thus it not clear whether there is a separate specialised WM and imagery component that deals with motor processing and storage of movements.

This question was approached via the most widely used visuo-spatial memory task, the Brooks Matrix task. Experiment I attempted to examine the cognitive processes involved in performance of this task which has been indicated in the literature as being an inherently difficult task that may involve other verbal and CE processes in addition to its assumed visuo-spatial component. Digits in this task were replaced by pictures/images of readily imageable objects in order to find out if their pictorial qualities would enhance retention. An aim of this manipulation was to try to devise a version of the Brooks Matrix that may in the long run enable tackling the issue of the visual vs spatial nature of the VSSP. However, the results showed that the visual quality of the material did not affect retention and that it may be the encoding and decoding processes that are more important for retention. After systematically varying the methods of presentation and recall between verbal and visual modalities, it was shown that visual, as opposed to verbal, encoding of the task leads to better recall whilst the visual decoding was no better than verbal decoding. Hence, the Brooks task turned to be a complex task that involves not just the retention of visual information but also other elements of the cognitive system that are necessary for the generation of visual images from verbal instruction during the acquisition phase and the generation of sentences from a visual image during the recall phase.

A process model of the task was proposed which assumes that with verbal presentation there is a heavy CE involvement to generate images from the verbal input and thus to switch attention between external input and internal memory input. That is, the translation between the verbal modality of input and the visuo-spatial modality of processing is assumed to be effected through heavy involvement of the CE in image generation. With visual presentation this CE function of image generation was removed. Hence, the conclusion of Experiment I was that it is the process of translating verbal instructions into a visual image which demands attentional resources whilst the decoding of the visual image into verbal statements is not much more difficult than visually decoding the image by placing cards representing the items on a real matrix..

Experiment II used a movement interference paradigm to examine this proposed process model which basically assumes that visual encoding of the Brooks Matrix is a function of the VSSP whilst verbal encoding is a function of both the VSSP and the CE. It was hypothesised that if movement interferes with a specialised visuo-spatial store then a spatial suppression task would interfere with both modalities of encoding. But if movement interferes with the CE, then the spatial suppression task would interfere with verbal, but not with visual, encoding. A second hypothesis was that if the VSSP is separable from the CE, then a CE loading task should interfere with verbal, but not with visual, encoding. Results supported only the first hypothesis. Spatial movement interfered with both presentation modalities but the predicted interaction did not occur. The CE task interfered with both verbal and visual encoding and hence did not support a dissociation in WM between the VSSP and the CE. The overall conclusion of this experiment was that CE resources appear to be required during active visuo-spatial encoding and that the VSSP is more than a simple or a passive buffer on which visuo-spatial information is imprinted. This conclusion lends support to previous indications in the literature such as that of Morris (1987) who proposed that the CE is 'coupled' to the VSSP during active encoding of spatial material and that the CE is probably required to operate the VSSP in most circumstances except during maintenance rehearsal.

In Experiment III, it was argued that the Brooks task has not been fully stripped of redundant verbal and CE processes. The use of items (digits or objects) to be placed in adjacent squares around the matrix was assumed to be redundant and thus the pattern TBR was presented as merely a series of directional adjectives. Results supported this assumption. A simplified method of visual recall was also examined in which a line, representing the retained visual image, is drawn on a real matrix. The methods of presentation and recall of this 'shortened' version of the task were systematically varied between verbal and visual modalities. Results replicated the results of Experiment (I) in terms of showing only a highly significant effect of encoding modality. Visual, as opposed to verbal, encoding led to better performance. The most simplified version of the Brooks Matrix task was examined by the fourth condition of this experiment in which no CE and no crossing or recrossing of the action-language bridge were required. This visually presented and recalled variant was assumed to be a pure visuo-spatial version that would enable the examination of movement interference with the minimum of contamination by CE and verbal processes.

Experiment IV used this simplified version of the task to examine movement interference during maintenance rehearsal of visuo-spatial information. This experiment examined the proposal by Reisberg & Logie (1993) that the VSSP has a rehearsal loop comprising an 'inner scribe' writing or feeding information to an 'inner eye'. This rehearsal loop was thought to be parallel to the rehearsal loop in verbal WM in which an inner voice articulates the verbal material and thus refreshes the contents of the inner ear, and they went so far as suggesting that this particular function of visuo-spatial imagery could in fact be motoric. It was hypothesised that if the VSSP involves such a 'motoric' rehearsal loop, then a spatial movement task would disrupt maintenance of visuo-spatial information. The spatial movement task was also predicted to interfere because if both tasks utilise the same WM resource, then carrying out this movement task during maintenance should overwrite the mental representation of the matrix information. It was also hypothesised that if the VSSP involves such a rehearsal loop, then a spatial movement task with an additional CE element should lead to further interference since the proposed refresh mechanism is assumed to be an active rehearsal process that involves executive and attentional resources.

Results of Experiment IV showed that only the spatial movement task with a CE element interfered with maintenance of the visuo-spatial information. One conclusion from that experiment was that since the regular spatial movement task did not interfere, the matrix information was most likely held in WM as a static pattern in a passive visual store that is not related to the planning and control of movement to targets in space. Since only a CE loading task (random spatial tapping) interfered with maintenance, it was concluded that the mental image was perhaps retained in a passive visual buffer that also requires general purpose resources for its operations.

A second conclusion was that there was no support for the proposal of Reisberg & Logie of an active rehearsal loop in the VSSP. The spatial movement task did not interfere with maintenance of the matrix information. If an 'inner scribe' related to movement control is involved in maintenance, then this spatially organised movement should have produced interference. This result supports similar results reported in the literature (e.g. Morris, 1987; Quinn, 1988a, 1991) which showed that maintenance of visuo-spatial information was impervious to movement interference. Such results suggest that movement does not disrupt the 'refresh' mechanism of the VSSP in the same way that a concurrent verbal task appears to disrupt the rehearsal loop in verbal WM (Annett, 1995). Thus, no support was found for the analogy between maintenance in the AL and the VSSP. Evidence from this study did not support the existence of a motoric rehearsal mechanism (inner scribe) in visuo-spatial WM and imagery that is equivalent to the motoric rehearsal mechanism (inner voice) in auditory WM and imagery.

As indicated in chapter 2, the VSSP has been conceptualised as complementary to the AL with the model of the AL being proposed as a model for the VSSP (e.g. Baddeley, 1990; Reisberg & Logie, 1993; Toms et al, 1994). This view has been supported by demonstrating the existence of some phenomena similar to those associated with the AL. These included the irrelevant visual input effect, the visual similarity effect, and the visual recency effect. However, unlike these phenomena which may suggest a close analogy with the AL, other phenomena have failed to show a parallel in the visuo-spatial domain. For instance, Smyth & Scholey (1992, 1994a) failed to show an analogy to the word length effect in visuo-spatial WM. In verbal WM the length of the words TBR affects the size of the memory span. Verbal span is decreased if the length of time required to say the item increased. Smyth & Scholey examined whether movement time between spatial targets predicts the number of spatial locations that are recalled. Results showed that spatial span can not be predicted by movement time, suggesting no simple analogy between verbal and spatial spans. Other differences between verbal and spatial spans have been reported in the literature. For instance, Vallar & Baddeley (1982) found that articulatory suppression during a recall interval did not affect the recall of 3 digits arguing that 3 digits were within the residual capacity that remains when verbal span is suppressed and therefore were maintained outside the articulatory rehearsal loop. In contrast, Smyth & Pendleton (1989) found that recall of 3 spatial items in order was affected by spatial movement. Hence, in visuo-spatial WM, spatial tapping affects both span and subspan whereas in verbal WM articulatory suppression does not affect subspan. One possible reason for this may be that spatial tapping is not analogous to articulatory suppression and uses some resources that are also involved in maintaining the residual spatial span. A second reason is that maintenance could be very different for verbal and spatial material (Smyth & Scholey, 1994a). Another difference between the two spans was reported by Isaacs & Vargha-khadem (1989) regarding the representation of order information. Spatial span can be carried out equally well backwards and forwards whereas verbal span cannot, suggesting a major difference in the way order information is dealt with.

In short, a spatial tapping task which has been used as a spatial suppression task was shown in this study to interfere with aural and visual encoding of the Brooks Matrix task (Experiment II) but not with maintenance of this visuo-spatial task. Regarding its interference with encoding, this result could be taken as indicating that the two tasks were using a visuo-spatial WM resource that is also involved in movement planning and control. This could indicate a close link between spatial representation and motor control and also emphasise a role for movement in spatial coding. Within Annett's (1982, 1994b) ALI model this task was supposed to interfere at encoding since the model assumes the involvement of motor processes in generating images such as in translating procedural knowledge into declarative knowledge or as in activating the action prototypes via appropriate verbal instructions leading to conscious images of action. Regarding the spatial tapping task not interfering with maintenance, this result could be interpreted as suggesting that either the matrix information was held in a passive visual imagery store that is not related to movement control. Or alternatively, this result could be taken as suggesting that the spatial tapping task is not a spatial suppression task that plays the spatial equivalent to the role of subvocalisation in verbal WM. This would support the indication by Baddeley (1992a) that it is not yet clear what process underlies the active rehearsal of visual imagery, playing the spatial equivalent to the role of subvocalisation in verbal WM. The system involved in controlling movement to targets in space and also the system involved in controlling eye movements have been implicated to provide the basis for the rehearsal of images but the available evidence is not conclusive.

7.3. A position on visuo-spatial WM

As discussed in chapters 1&2, during the last two decades there has been intensive research directed towards examining the WM model proposed by Baddeley & Hitch (1974) which proposes a tripartite WM system instead of a single STM system. Two independent subsystems were identified, the AL and the VSSP, and which are thought to be controlled by an attentional supervisory system, the CE. The VSSP which was assumed to be responsible for retention and manipulation of visuo-spatial information and images, did not receive much attention in the beginning and most research was directed towards developing a model for the AL. However, lately this trend has changed and the VSSP has become the subject of intensive research that has generated a number of debates (e.g. Logie, 1989, 1991; Morris, 1987; Quinn, 1988a, 1991, 1994). This thesis attempted to examine this WM subsystem and in particular it attempted to shed some light on the debate regarding the role of movement in this WM component.

Objective experimental results of this study, along with the subjective reports of subjects, appear to support the existence of such a WM subsystem that is involved in processing and retention of visuo-spatial images. The basic question asked was whether movement interferes with visuo-spatial processing because of a shared visuo-spatial temporary resource or because of the CE involvement. The answer to this question does not seem to be very straightforward. A straightforward answer would need the demonstration of a complete dissociation between the CE and the VSSP. However, as the results of this research showed, CE resources appear to be required for the operation of the VSSP during encoding and probably during image maintenance. The results lend support to previous conclusions in the literature (e.g. Logie et al, 1990) by arguing for a separate specialised visuo-spatial WM resource that also requires a certain amount of monitoring by CE resources.

As discussed in chapter 2, there is growing evidence in both behavioural and neuropsychological domains which suggest that visuo-spatial WM may not comprise a single system but rather two separate visual and spatial subsystems. The visual component is assumed to be a passive visual store involved in retention of static visual material whereas the spatial element is assumed to be an active process that is involved in retention of spatial material and in the control of movement. Results of this study may be taken as supporting this distinction if we assume that encoding the Brooks material was a function of the spatial component and thus was vulnerable to interference by spatial tapping, whereas maintenance of the Brooks material was a function of the visual component and thus was impervious to interference by spatial tapping. This argument would have been stronger if a purely visual interference task (e.g. irrelevant pictures) had been used and was shown to interfere with maintenance.

From the results of this study, the passive visual component of visuo-spatial WM appears also to require some CE element (e.g. a visual monitoring device) for its operations. This component may turn out to be similar to the concept of a visual buffer proposed by Kosslyn (1980) in his theory of visual imagery. The buffer is thought to hold visual images that can be generated from LTM or as a result of encoding through visual perception. The buffer is thought to be of a limited capacity, that its contents are subject to decay unless refreshed presumably by a process of "visual rehearsal", and that contents are prone to interference from any material that may enter the buffer.

This issue of visuo-spatial WM having two components was recently discussed by Vecchi, Monticellai & Cornoldi (1995) who argued for a distinction between a passive memory store and an active imagery process. The passive store is able to retain visuo-spatial material without performing any modifications on it whilst active imagery operations come into play when people have to mentally create, manipulate or reorganise visuo-spatial material and images. Their results suggested that in imagery tasks, these two components can be dissociated in the architecture of visuo-spatial WM and that they are partly loading on different capacity limitations.

In sum, the model of the VSSP is increasingly becoming sophisticated with some studies demonstrating the existence of phenomena that support an analogy with the model for the AL. Like the AL, the VSSP may comprise a passive sensory store and an active motoric element. Also, like the AL, there is evidence for the effects of visual similarity, visual recency, and irrelevant visual input. However, the analogy appears to break down on issues such as finding an analogy to the word length effect and more importantly on the issue of maintenance rehearsal. As discussed in chapter 6, there has been so far no support for the existence of a refresh mechanism in the VSSP that is analogous to the rehearsal loop in verbal WM.

Finally, the results of this study appear to highlight the importance of the CE in cognitive functioning and to support, to some extent, the view of WM expressed by Logie (1995) in which WM is viewed as a cognitive architecture comprising a CE and cache memories, with visual imagery seen as a suite of programs which can be implemented on that architecture. Logie indicated that various descriptions of the CE have been put forward such as a conceptual ragbag, an area of residual ignorance, a scheduler for allocating attention (Baddeley, 1986) and a flexible resource that can be used for storage and for processing (Baddeley, 1986; Just & Carpenter, 1992). However, Logie argued that the last one best captures the spirit of its function with the CE acting as "a form of flexible processing 'neuroware' which can run a variety of software including the generation and manipulation of visual imagery as well as language comprehension and heuristics for problem solving" (1995, p.131). The CE, according to Logie, is supported by storage mechanisms which are a visual cache and a verbal cache. Each of these two mechanisms offers temporary retention of material that is required in on-line processing in the executive. The caches allow humans to lay information to one side and return to it a few seconds later after processing segments of the information that are in the conscious image. Moreover, relatively automated procedures such as regenerating or subvocally rehearsing can be implemented to assist each cache in maintaining its contents.

In addition, Logie presented a modified view of visuo-spatial WM which he claims to be different from what has been assumed in imagery research or in the WM literature. In short, this modified view states that visuo-spatial WM is a system that comprises two temporary stores, one visual and the other spatial. These two separate stores are charged with the retention of visual and spatial material respectively whilst the generation and manipulation of conscious visual images relies on executive functions. The route from visual input to both stores is via LTM representations of the visual form of objects or the spatial information about a dynamic scene. When these LTM representations are activated, the information enters either the visual or the spatial part of the system depending on the nature of the activated information. This view of WM not being a gateway to LTM is consistent with the indication by Smyth et al (1994) that information in WM at any time is already in LTM in one sense and that the use of the term WM rather than STM implies that the information is held for use, and not just because it has not been processed enough to get into LTM.

The visual store is seen as being subject to decay and interference from new information whilst the spatial store is seen as a system that can be used to plan movement and also to rehearse the contents of the visual store. The spatial system can extract information from the visual store to allow for targeted movement. The link with visual imagery, according to Logie, is that the spatial and visual components provide temporary storage of information from which the CE can extract material which is relevant to the current task. The CE can also access semantic information activated from LTM and can retrieve phonological information being held temporarily in the AL.

7.4. Implications & directions for future work

This study investigated movement interference in visuo-spatial WM in an attempt to shed some light on the broader issue of whether there is a specialised WM and imagery resource that deals with the encoding and representation of movements. The study of how movements and actions are represented and stored in WM, and thus how motor skills are encoded, has wide implications for the acquisition of motor skills. During the early 1950s researchers in motor skills were among the first to see the relevance of information processing concepts to our understanding of human motor performance and subsequent researchers have explored in some depth the relations between cognition and skill. For instance, Fitts (1964) proposed a model of the phases of skill learning which has influenced training theory ever since. He addressed the problem of learning complex skills and drew attention to the importance of cognitive processes such as understanding principles and developing action plans and strategies. Adams (1971) proposed that two traces represent each movement in a performer's repertoire- a memory trace for initiating and selecting movement and a perceptual trace used to determine the extent of movement and to detect and correct error by providing a comparison for feedback. Schmidt (1975) proposed a schema theory of discrete motor skill learning which built on schema theory in perception as well as the strengths of Adams' closed-loop theory. He identified two elements of the motor response schema, recall schema responsible for response production and recognition schema that assessed the correctness of response.

In short, as indicated by Annett (1991b, 1994a) there is increasing recognition of the importance of cognitive processes in the generation and control of action and in the acquisition of skill, and information processing concepts provide the best available framework within which to analyse specific skills. The role of STM for movements received research attention during the 1960s and 1970s. Because the aim of any training session for skill acquisition is to enhance future movement reproduction, the early attention focused on rehearsal of movement information in the hope of understanding how memory for movement becomes permanent (e.g. Posner, 1967). Other work in this area has dealt with how movement was encoded and the different encoding strategies employed by subjects. However, Salmoni (1989) argued that it is still fair to conclude that the role of WM in the associative phase (or any phase) of skill learning is mostly hypothetical at this point. Adams (1987) indicated that there is still a void in the failure to relate higher processes to action and he suggested that there are several lines of research which may help solve this problem. These are observational learning of movement, the role of mental imagery in action, and the relationship between language and action. Annett (1994a) pointed out that a well-articulated theory of cognitive motor learning is lacking, in part due to the lingering influence of behaviourism on theorising about learning, and that the key to cognitive motor learning lies in elucidating the way in which learned skills are represented in WM. Thus, as indicated by Colley (1989), much more needs to be learned about the role of WM in movement control and acquisition. There is a large literature on WM and verbal tasks (see chapter 1 & Baddeley, 1986) but very much less on spatial WM and the involvement of WM in skill acquisition.

To conclude, this thesis presented an attempt to tackle movement interference in visuo-spatial WM through a systematic series of experiments that examined the most widely used memory task in this domain, the Brooks Matrix task. The interference effects of various movement tasks on newly developed variants of this task were examined. Two broad issues were investigated. The first is the relationship between the VSSP and the CE and the results showed that the CE resources are required for the operation of the VSSP and hence a complete dissociation between these two systems is unlikely. The second issue was whether the VSSP is maintained by a rehearsal loop comprising an 'inner scribe' feeding information to an 'inner eye' and that is analogous to the refresh mechanism in verbal WM. The results did not support this proposal. The rehearsal mechanism does not appear to involve the system responsible for control of movement as suggested by Logie (1991). The results also demonstrated that the standard Brooks Matrix task is an inherently difficult task that heavily involves CE and verbal elements in addition to its assumed visuo-spatial component. Movement interference in visuo-spatial WM in general and during image maintenance in particular needs a good deal more of carefully designed experimental work before the link between spatial representation and motor control is fully understood. Future research may use techniques developed here to clarify more the relationship between the VSSP and the CE. The simplified visually presented and recalled variant of the Brooks Matrix task developed here could be used as a primary visuo-spatial task to tackle this issue. As Experiment IV showed, the error rate on this variant was relatively low and thus future work may use a 5x5 matrix instead of the standard 4x4 matrix. Other tasks developed here may also be helpful. These include rhythmic tapping and random spatial tapping. The latter has the advantage of being comparable to the regular spatial "suppression" task except in regard to the one aspect that should be varied (CE loading). The characteristics of the VSSP are increasingly becoming more understood as a result of more research being conducted in this area during the past decade or so. However, this visuo-spatial WM domain needs more work in order to firmly establish a model for the VSSP. A viable research strategy is to derive evidence from a number of sources and experimental manipulations and paradigms that will converge on a coherent view of the VSSP. Such a strategy has proven successful with the development of a model for verbal WM.

References

Adams, J. A. (1971). A closed-loop theory of motor learning. Journal of Motor Behaviour, 3, 111-149.

Adams, J. A. (1987). Historical review and appraisal of research on the learning, retention, and transfer of motor skills. Psychological Bulletin, 101, 41-74.

Allen, T. W., Marcell, M. M., & Anderson, P. (1978). Modality-specific interference with verbal and nonverbal stimulus information. Memory & Cognition, 6, 184-188.

Allport, D. A. (1977). On knowing the meaning of words we are unable to report: the effects of visual masking. In S. Dornic (Ed.), Attention and performance VI. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Allport, D. A. (1980). Attention and performance. In G. Claxton (ed.), Cognitive Psychology: New Directions. London: Routledge & Kegan Paul.

Anderson, R. A., Essick, G. K. & Siegel, R. M. (1987). Neurons of area 7 activated by both visual stimuli and oculomotor behaviour. Experimental Brain Research, 67, 316-322.

Annett, J. (1982). Action, Language and Imagination. In L. Wankel & R. B. Wilberg (eds), Psychology of Sport and Motor Behaviour: Research and Practice (pp.271-281). Edmonton: University of Alberta.

Annett, J. (1983). Motor learning: a cognitive psychological viewpoint. In H. Reider, K. Bos, H. Mechling, & K. Reischle (Eds), Motor learning and movement behaviour (pp. 220-230), Schorndorf: Karl Hofman.

Annett, J. (1985). Motor Learning: A Review. In H. Heuer, U. Kleinbeck & K-H. Schmidt (eds). Motor Behaviour: Programming, Control and Acquisition, pp.189-212. Berlin: springer-Verlag.

Annett, J. (1986). On knowing how to do things. In H. Heuer & C. Fromm (eds.). Generation and Modulation of Action Patterns, pp.187-200. Berlin: Springer-Verlag.

Annett, J. (1989). Training skilled performance. In A. M. Colley & J. R. Beech (eds). Acquisition and performance of cognitive skills. London: John Wiley & Sons.

Annett, J. (1990). Relations between verbal and gestural explanations. In G. R. Hammond (ed.). Cerebral Control of Speech and Limb Movements, pp. 295-314. Amsterdam: Elsevier Science publishers B.V.

Annett, J. (1991a). Imaginary Actions. Paper delivered to the Eighth Annual Conference of the Cognitive Psychology Section of the British Psychological Society, Oxford, 6-8 September 1991.

Annett, J. (1991b). Skill acquisition. In J. E. Morrison (ed.). Training for performance: Principles of applied human learning, pp.13-51. Chichester: John Wiley & Sons.

Annett, J. (1994a). Motor Skills. In A. M. Colman (Ed). Companim Encyclopaedia of Psychology. London: Routledge & Kegan Paul.

Annett, J. (1994b). The learning of motor skills: Sports science and ergonomics perspectives. Ergonomics, 37, 1, 5-16.

Annett, J. (1994c). On Knowing How to Do things. Paper delivered to Satellite Symposium on Mental Representation of Motor Acts. 17th. Annual Meeting of the European Neuroscience Association, Vienna, 4-8 September 1994.

Annett, J. (1995). Motor imagery: perception or action? Neuropsychologia, 33, 11, 1395-1417.

Annett, J., & Smith, R. (1988). Motor Imagery in Parkinson's disease. In C. Cornoldi (ed.), Imagery & Cognition. Pre-proceedings of the Second International Workshop on Imagery and Cognition, University of Padua, Italy, 21-23 September 1988, pp.373-385.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence (ed.). The psychology of learning and motivation: advances in research and theory Vol. 2, pp.89-195. New York: Academic Press.

Atkinson, R. C., & Shiffrin, R. M. (1971). The control of short-term memory. Scientific American, 225, 82-90.

Atwood, G. E. (1971). An experimental study of visual imagination and memory. Cognitive Psychology, 2, 290-299.

Avons, S. E., & Phillips, W. A. (1987). Representation of matrix patterns in long- and short-term visual memory. Acta Psychologica, 65, 227-246.

Baddeley, A. D. (1966a). Short-term memory for word sequences as a function of acoustic, semantic, and formal similarity. Quarterly Journal of Experimental Psychology, 18, 362-365.

Baddeley, A. D. (1966b). The influence of acoustic and semantic similarity on long-term memory for word sequences. Quarterly Journal of Experimental Psychology, 18, 302-309.

Baddeley, A. D. (1966c). The capacity for generating information by randomisation. Quarterly Journal of Experimental Psychology, 18, 119-130.

Baddeley, A. D. (1968). A three minute reasoning test based on grammatical transformation. Psychonomic Science, 10, 341-342.

Baddeley, A. D. (1972). Retrieval rules and semantic coding in short-term memory. Psychological Bulletin, 78, 379-385.

Baddeley, A. D. (1981). The Concept of working memory: A view of its current state and probable future development. Cognition, 10, 17-23.

Baddeley, A. D. (1986). Working memory. Oxford: Oxford University Press.

Baddeley, A. D. (1988). Imagery and Working Memory. In M. Denis, J. Engelkamp & J. T. E. Richardson (eds), Cognitive and Neuropsychological Approaches to Mental Imagery (pp.169-180). Dordrecht: Martinus Nijhoff Publishers, NATO ASI series.

Baddeley, A. D. (1990). Human memory: Theory and practice. Hove, UK: Lawrence Erlbaum Associates Ltd.

Baddeley, A. D. (1992a). Is Working Memory Working? The fifteenth Bartlett Lecture. Quarterly Journal of Experimental Psychology, 44A, 1-31.

Baddeley, A. D. (1992b). Working Memory: The Interface Between Memory & Cognition. Journal of Cognitive Neuroscience, 4, 3, 281-288.

Baddeley, A. D. (1992c). Working Memory. Science, 225, 255-259.

Baddeley, A. D. (1993). Working memory or working attention? In A. D. Baddeley & L. Weiskrantz (eds.), Attention: selection, awareness, and control, A tribute to Donald Broadbent, pp.152-170. Oxford: Oxford University Press.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. A. Bower (ed.), The Psychology of learning and motivation, Vol.8, pp.47-89. New York: Academic Press.

Baddeley, A. D., & Lieberman, K. (1980). Spatial Working Memory. In R. S. Nickerson (Ed.), Attention and performance VIII, pp.521-539. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Baddeley, A. D., & Logie, R. H. (1992). Auditory imagery and working memory. In D. Reisberg (ed.), Auditory imagery, pp.179-197. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Baddeley, A. D., Bressi, S., Della Sala, S., Logie, R. H., & Spinnler, H. (1991). The decline of working memory in Alzheimer's disease: A longitudinal study. Brain, 114, 2521-2542.

Baddeley, A. D., Grant, W., Wight, E., & Thomson, N. (1975b). Imagery and visual working memory. In P.M.A. Rabbit & S. Dornic (eds.), Attention and performance V, pp.205-217. London: Academic Press.

Baddeley, A. D., Lewis, V. J., Eldridge, M. & Thomson, N. (1984). Attention and retrieval from long-term memory. Journal of Experimental Psychology: general, 113, 518-540.

Baddeley, A. D., Logie, R. H., Bressi, S., Della Sala, S., & Spinnler, H. (1986). Dementia and working memory. Quarterly Journal of Experimental Psychology, 38A, 603- 618.

Baddeley, A. D., Papagno, C., & Vallar, G. (1988). When long-term learning depends on short-term storage. Journal of Memory and Language, 27, 586-595.

Baddeley, A. D., Thomson, N., & Buchanan, M. (1975a). Word length and the structure of short-term memory. Journal of Verbal Learning and Verbal Behaviour, 14, 575-589.

Bahrick, H. P., & Shelly, C. (1958). Time-sharing as an index of automation. Journal of Experimental Psychology, 56, 288-293.

Barber, P. J. (1989). Executing two tasks at once. In A. M. Colley & J. R. Beech (eds.). Acquisition and performance of cognitive skills. London: John Wiley & Sons.

Barnard, P. (1985). Interacting cognitive subsystems: A Psycholinguistic approach to short-term memory. In A. W. Ellis (ed.), Progress in the Psychology of Language, Vol. 2. Hillsdale, NJ: Lawrence Erlbaum Associates.

Bat-Zion, N. (1986). The relation of imagery to other mental abilities. In D. Russel, D. F. Marks & J. T. .E. Richardson (eds.), Imagery 2. Dunedin: Human Performance associates.

Berger, G. H., & Gaunitz, S. C. B. (1979). Self-rated imagery and encoding strategies in visual memory. British Journal of Psychology, 70, 21-24.

Bergstrom, K., & Hiscock, M. (1988). Factors influencing ocular motility during the performance of cognitive tasks. Canadian Journal of Psychology, 42, 1, 1-23.

Betts, G. H. (1909). The distribution and functions of mental imagery. New York: Columbia University. Teachers College Contributions to Education series, 26, pp.1-99.

Bihrle, A. M., Bellugi, U., Delis, D., & Marks, S. (1989). Seeing either the forest or the trees: Dissociation in visuo-spatial processing. Brain & Cognition, 11, 37-49.

Broadbent, D. E. (1958). Perception and communication. London: Pergamon Press.

Broadbent, D. E., & Broadbent, M. H. P. (1981). Recency effects in visual memory. Quarterly Journal of Experimental Psychology, 33A, 1-15.

Brooks, L. R. (1967). The suppression of visualisation by reading. Quarterly Journal of Experimental Psychology, 19, 289-299.

Brooks, L. R. (1968). Spatial and verbal components in the act of recall. Canadian Journal of Psychology, 22, 349-368.

Cheng, P. W. (1985). Restructuring vs automaticity: Alternative accounts of skill acquisition. Psychological Review, 92, 414-423.

Cohen, B. H., & Salsona, M. (1990). The advantage of being habitual visualiser. Journal of Mental Imagery, 14, 101-112.

Colley, A. M. (1989). Learning motor skills: integrating cognition and action. In A. M. Colley & J. R. Beech (eds.), Acquisition and Performance of Cognitive Skills. London: John Wiley & Sons.

Conrad, R. (1964). Acoustic confusion in immediate memory. British Journal of Psychology, 55, 75-84.

Cooper, L. A., & Shepard, R. N.(1973). Chronometric studies of the rotation of mental images. In W. G. Chase (Ed.), Visual Information Processing. New York: Academic Press.

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. Journal of Verbal Learning & Verbal Behaviour, 11, 671-684.

Craik, F. I. M., & Watkins, M. J. (1973). The role of rehearsal in short-term memory. Journal of Verbal Learning & Verbal Behaviour, 12, 599-607.

Dalrymple-Alford, J. C., Kalders, A. S., Jones, R. D., & Watson, R. W. (1994). A central executive deficit in patients with Parkinson's disease. Journal of Neurology, Neurosurgery, and Psychiatry, 57, 360-367.

De Renzi, E., & Nichelli, P. (1975). Verbal and nonverbal short-term memory impairment following hemispheric damage. Cortex, 11, 341-353.

Dean, G. M. (1994). Imagery and spatial ability. PhD thesis, Lancaster University.

Dean, G. M., & Morris, P. E. (1990, unpublished manuscript). A factor analysis of the Vividness of Visual Imagery Questionnaire.

Dean, G. M., & Morris, P. E. (1991). Imagery and spatial ability: when introspective reports predict performance. In R. H. Logie & M. Denis (eds.), Mental images in human cognition, pp.331-347. Amsterdam: Elsevier Publishers B.V.

Della Sala, S., & Logie, R. H. (1993). When working memory does not work: The role of working memory in neuropsychology. In F. Boller & H. Spinnler (eds.), Handbook of Neuropsychology, vol. 8, pp.1-62. Amsterdam: Elsevier Publishers B.V.

Della Sala, S., Laiacona, M., Spinnler, H., & Trivelli, C. (1992). Is autobiographical memory impairment due to a deficit of recollection? In M.A. Conway, D.C. Rubin, H. Spinnler, & W.A. Wagenaar (Eds), Theoretical perspectives on autobiographical memory (pp.451-472). The Netherlands: Kluwer.

Denis, M. (1987). Individual imagery difference and prose processing. In M. A. McDaniel & M. Pressley (Eds), Imagery and related mnemonic processes: Theories, individual differences, and applications, pp.204-217. New York: Springer-Verlag.

Ellis, N. C. (1991). Word meaning and the links between the verbal system and modalities of perception and imagery. In R. H. Logie & M. Denis (Eds), Mental images in human cognition, pp.313-329. Amsterdam: Elsevier Publishers B.V.

Ellis, N. C., & Hennelly, R. A. (1980). A bilingual word-length effect: Implications for intelligence testing and the relative ease of mental calculation in Welsh and English. British Journal of Psychology, 71, 43-52.

Engelkamp, J. (1988). Images and Actions in Verbal Learning. In M. Denis, J. Engelkamp & J. T. E. Richardson (eds.), Cognitive and Neuropsychological Approaches to Mental Imagery (pp.297-306). Dordrecht: Martinus Nijhoff Publishers, NATO ASI series.

Engelkamp, J. (1991). Memory of Action Events: Some Implications for Memory Theory and for Imagery. In C. Cornoldi & M. A. McDaniel (Eds.), Imagery & Cognition, pp.183-219. Berlin: Springer-Verlag.

Evans, F. J. (1978). Monitoring attention deployment by random number generation: An index to measure subjective randomness. Bulletin of the Psychonomic Society, 12, 35-38.

Farah, M. J. (1988). Is visual Imagery really visual? Overlooked evidence from neuropsychology. Psychological Review, 95, 307-317.

Farah, M. J. (1989). Mechanisms of imagery perception interaction. Journal of Experimental Psychology: Human Perception & Performance, 15, 203-211.

Farah, M. J., Hammond, K. M., Levine, D. N., & Calvanio, R. (1988). Visual and spatial mental imagery: Dissociable systems of representation. Cognitive Psychology, 20, 439-462.

Farmer, E. W., Berman, J.V.F. & Fletcher, Y. L. (1986). Evidence for a visuo-spatial scratch-pad in working memory. Quarterly Journal of Experimental Psychology, 38A, 675-688.

Fitts, P. M. (1964). Perceptual-motor skill learning. In A. W. Melton (ed.), Categories of Human Learning. New York: Academic Press.

Frick, R. W. (1988). Issues of representation and limited capacity in the visuo-spatial sketchpad. British Journal of Psychology, 79, 289- 308.

Frith, C. D., & Lang, R. J. (1978). Learning and reminiscence as a function of target predictability in a two-dimensional tracking task. Quarterly Journal of Experimental Psychology, 31, 103-109.

Gathercole, S. E., & Baddeley, A. D. (1990). The role of phonological memory in vocabulary acquisition: a study of young children learning arbitrary names of toys. British Journal of Psychology, 81, 439-454.

Gathercole, S. E., Willis, C., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. Developmental Psychology, 28, 887-898.

Gilhooly, K. J., Logie, R. H., Wetherick, N. E., & Wynn, V. (1993). Working memory and strategies in syllogistic-reasoning tasks. Memory & Cognition, 21, 115-124.

Glanzer, M., & Cunitz, A. R. (1966). Two storage mechanisms in free recall. Journal of Verbal Learning & Verbal Behaviour, 5, 351-360.

Grossi, D., & Becker, J. T. (1994). Visuospatial Imagery in Alzheimer Disease. Perceptual & motor skills, 78, 867-874.

Gur, R. C., & Hilgard, E. R. (1975). Visual imagery and the discrimination of differences between altered pictures simultaneously and successively presented. British Journal of Psychology, 66, 341-343.

Hall, C. R. (1980). Imagery for movement. Journal of Human Movement Studies, 6, 252-264.

Halliday, M. S., & Hitch, G. J. (1988). Developmental applications of working memory. In G. Claxon (ed.), Growth Points in Cognition. London: Routledge & Kegan Paul.

Hanley, J. R., Young, A.W. & Pearson, N. A. (1991). Impairment of the Visuo-Spatial Sketchpad. Quarterly Journal of Experimental Psychology, 43A, 101-125.

Hayes, N. A., & Broadbent, D. E. (1988). Two modes of learning for interactive tasks. Cognition, 28, 249-276.

Heuer, F., Fischman, D. & Reisberg, D. (1986). Why does vivid imagery hurt colour memory?. Canadian Journal of Psychology, 40, 161-175.

Heuer, H., & Wing, A. M. (1984). Doing Two Things at Once: Process Limitations and Interactions. In M. M. Smyth & A. M. Wing (eds.), The Psychology of Human Movement. New York: Academic Press.

Hitch, G. J. (1984). Working Memory. Psychological Medicine, 14, 265-271.

Hitch, G. J., & Halliday, M. S. (1983). Working memory in children. Philosophical Transactions of the Royal Society, London B 302, 325-340.

Hitch, G. J., Halliday, S., Schaafstal, A. M. & Schraagen, J. M. (1988). Visual working memory in young children. Memory & Cognition, 16, 120-132.

Hitch, G. J., Woodin, M. E. & Baker, S. (1989). Visual and phonological components of working memory in children. Memory & Cognition, 17, 175-185.

Holding, D. H. (1994). Sharing verbal and visuospatial resources in Working Memory. The Journal of General Psychology, 120, 245-256.

Housner, L. D. (1984). The role of visual imagery in recall of modelled motoric stimuli. Journal of sport Psychology, 6, 148-158.

Hue, C. & Ericsson, J. R. (1988). Short-term memory for Chinese characters and radicals. Memory & Cognition, 16, 196-205.

Hunt, E., & Lansman, M. (1981). Individual differences in attention. In R. J. Sternberg (ed.), Advances in the Psychology of Human Intelligence, Vol.1, 207-254. Hillsdale, NJ: Lawrence Erlbaum Associates.

Idzikowski, C., Baddeley, A. D., Dimbleby, R. D. & Park, S. (1983). Eye movements and Imagery. Paper presented to the Experimental Psychology Society, April.

Isaac, A., Marks, D. F., & Russell D. G. (1986). An Instrument for Assessing Imagery of Movement: The Vividness of Movement Imagery Questionnaire (VMIQ). Journal of Mental Imagery, 10, 23-30.

Isaacs, E. B. & Vargha-Khadem, F. (1989). Differential course of development of spatial and verbal memory span: A normative study. British Journal of Developmental Psychology, 7, 377-380.

James, W. (1890). Principles of Psychology, Vol. 1. (1905 ed). London: Macmillan & Co.

Johnson, P. (1982). The functional equivalence of imagery and movement. Quarterly Journal of Experimental Psychology, 34A, 349-365.

Johnson, P. (1984). The Acquisition of Skill. In M. M. Smyth & A. M. Wing (eds.), The Psychology of Human Movement, pp.215-240. New York: Academic Press.

Jones, G. V. (1976). A Fragmentation hypothesis of memory: Cued recall of pictures and of sequential position. Journal of Experimental Psychology: General, 105, 277-293.

Jones, G. V. (1985). Deep dyslexia, imageability and ease of prediction. Brain and Language, 24, 1-19.

Jones, G. V. (1988). Imageability and a performance measure of predictability. In M. Denis, J. Engelkamp, & J.T.E. Richardson (Eds), Cognitive and neuropsychological approaches to mental imagery. Dordrecht: Martinus Nijhoff, B.V. NATO ASI series.

Just, M., & Carpenter, P. (1992). A capacity theory of comprehension: Individual differences in working memory. Psychological Review, 99, 122-149.

Kosslyn, S. M. (1975). Information representation in visual images. Cognitive Psychology, 7, 31-37.

Kosslyn, S. M. (1980). Image and Mind. Cambridge, Mass: Harvard University press.

Kosslyn, S. M. (1991). A cognitive neuroscience of visual cognition: Further developments. In R. H. Logie & M. Denis (Eds.), Mental images in human cognition, 351-381. Amsterdam: Elsevier.

Kosslyn, S. M., Flynn, R. A., Amsterdam, J. B. & Wang, G. (1990). Components of high-level vision: A cognitive neuroscience analysis and accounts of neurological syndromes. Cognition, 34, 203-277.

Kruley, P., Sciama, S. C. & Glenberg, A. M. (1994). On line processing of textual illustrations in the Visuospatial sketchpad: Evidence from dual-task studies. Memory & Cognition, 22, 261-272.

Locke, J. (1690). An essay concerning human understanding. London (1st ed.).

Logie, R. H. (1986). Visuo-spatial processing in working memory. Quarterly Journal of Experimental Psychology, 38A, 229-247.

Logie, R. H. (1988). Limitations on visualisation. In C. Cornoldi (ed.), Imagery & Cognition. Pre-proceedings of the Second International Workshop on Imagery and Cognition, University of Padua, Italy, 21-23 Sept., pp.31-41.

Logie, R. H. (1989). Characteristics of visual short-term memory. European Journal of Cognitive Psychology, 1, 275-284.

Logie, R. H. (1991). Visuo-spatial short-term memory: Visual working memory or visual buffer? In C. Cornoldi & M. A. McDaniel (Eds.), Imagery & Cognition, pp.77-102. Berlin: Springer-Verlag

Logie, R. H. (1993). Working memory in everyday cognition. In G. M. Davies & R. H. Logie (Eds.), Memory in everyday life, pp.173-218. Amsterdam: Elsevier Publishers B.V.

Logie, R. H. (1993b). Mental manipulation, visual working memory & executive processes. Paper presented at the joint meeting of the Canadian Society for Brain, Behaviour & Cognitive science with the Experimental Psychology Society. Univ. of Toronto, 15-17 July 1993.

Logie, R. H. (1995). Visuo-spatial working memory. Hove, UK: Lawrence Erlbaum Associates Ltd.

Logie, R. H., & Baddeley, A. D. (1990). Imagery and Working Memory. In P. J. Hampson, D. F. Marks & J.T.E. Richardson (eds.), Imagery: Current developments. London: Routledge.

Logie, R. H., & Baddeley, A.D. (1987). Cognitive processes in counting. Journal of Experimental Psychology: Learning, Memory, and Cognition, 13, 310-326.

Logie, R. H., & Marchetti, C. (1991). Visuo-spatial working memory: Visual, spatial or central executive? In R. H. Logie & M. Denis (Eds.), Mental images in human cognition, pp.105-115. Amsterdam: Elsevier Publishers B.V.

Logie, R. H., & Salway, A. F. S. (1990). Working memory and modes of thinking: A secondary task approach. In K. Gilhooly, M. Keane, R. Logie, & G. Erdos (Eds.), Lines of thinking: Reflections on the psychology of thought, Vol. 2, pp.99-113. Chichester: Wiley.

Logie, R. H., Baddeley, A. D., Mane, A., Donchin, E. & Sheptak, R. (1989). Working memory in the acquisition of complex cognitive skills. Acta Psychologica, 71, 53-87.

Logie, R. H., Zucco, G. M. & Baddeley, A. D. (1990). Interference with visual short -term memory. Acta Psychologica, 75, 55-74.

MacLeod, C. M. (1986). Cross-modal recognition of pictures and descriptions without test-appropriate encoding. Bulletin of the Psychonomic Society, 24, 21-24.

Marks, D. F. (1972). Individual differences in the vividness of visual imagery and their effect on function. In P. W. Sheehan (ed.). The function and nature of imagery, pp.83-108. New York: Academic press.

Marks, D. F. (1973a). Visual imagery differences in the recall of pictures. British Journal of Psychology, 64, 17-24.

Marks, D. F. (1973b). Visual imagery differences and eye movements in the recall of pictures. Perception & Psychophysics, 14, 407-412.

Marks, D. F. (1977). Imagery and consciousness: A theoretical review from an individual differences perspective. Journal of Mental Imagery, 1, 275-290.

Marks, D. F. (1983a). In defence of imagery questionnaires. Scandinavian Journal of Psychology, 24, 243-246.

Marks, D. F. (1983b). Mental imagery and consciousness: A theoretical review. In A. A. Sheikh (Ed.), Imagery: Current Theory, Research and Application, pp.96-130. New York: Wiley.

Marks, D. F. (1985). Imagery differences: An overview of research on visual imagery vividness. In D. F. Marks & D. G. Russell (Eds.), Imagery 1, pp.1-4. Dunedin, New Zealand: Human Performance Associates.

Marks, D. F. (1989a). Bibliography of research utilising the Vividness of Visual Imagery Questionnaire. Perceptual & Motor Skills, 69, 707-718.

Marks, D. F. (1989b). Construct validity of the Vividness of Visual Imagery Questionnaire. Perceptual & Motor Skills, 69, 459-465.

McKelvie, S. J. (1990). The Vividness of Visual Imagery Questionnaire: Commentary on the Marks-Chara debate. Perceptual & Motor Skills, 70, 551-560.

McKelvie, S. J. (1994). The Vividness of Visual Imagery Questionnaire as a predictor of facial recognition memory performance. British Journal of Psychology, 85, 93-104.

McKelvie, S. J., & Demers, E. G. (1979). Individual differences in reported visual imagery and memory performance. British Journal of Psychology, 70, 51-57.

McLeod, P. D. (1977). A dual-task modality effect: Support for multi-processor models of attention. Quarterly Journal of Experimental Psychology, 29, 651-668.

Milner, B. (1966). Amnesia following operation on the temporal lobes. In C.W. Whitty & O.L. Zangwill (Eds), Amnesia. London: Butterworths.

Milner, B. (1970). Memory and the medial temporal regions of the brain. In K.H. Pribram & D.E. Broadbent (Eds), Biology of memory. New York: Academic Press.

Moar, I. (1978). Mental triangulation and the nature of internal representations of space. Unpublished PhD thesis, University of Cambridge.

Morris, N. (1986a). Working memory, 1974-1984: A review of a decade of research. Current Psychological Research & Reviews, 5, 281-295.

Morris, N. (1986b). Working Memory Constellations. Unpublished PhD Thesis, University of Durham, UK.

Morris, N. (1987). Exploring the visuo-spatial scratch pad. Quarterly Journal of Experimental Psychology, 39A, 409-430.

Morris, N. (1989). Spatial monitoring in visual working memory. British Journal of Psychology, 80, 333-349.

Morris, N., & Jones, D. M. (1990). Memory updating in working memory: The role of the central executive. British Journal of Psychology, 81, 111-121.

Murray, D. J. (1968). Articulation and acoustic confusability in short-term memory. Journal of Experimental Psychology, 78, 679-684.

Naveh-Benjamin, M. (1987). Coding of spatial information: An automatic process? Journal of Experimental Psychology: Learning, memory, and cognition, 13, 595-605.

Naveh-Benjamin, M. (1993). Commentary: Ecological perspective of working memory. In G. M. Davies & R. H. Logie (Eds.), Memory in everyday life, pp.231-239. Amsterdam: Elsevier Publishers B.V.

Naveh-Benjamin, M., & Ayres, T. J. (1986). Digit span, reading rate, and linguistic relativity. Quarterly Journal of Experimental Psychology, 38, 739-751.

Navon, D., & Gopher, D. (1979). On the economy of the human processing system. Psychological Review, 86, 214-255.

Neisser, U. (1970). Visual imagery as process and experience. In J. S. Antrobus (ed.), Cognition and Affect. Boston: Little, Brown.

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes, Cognitive Psychology, 7, 44-64.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behaviour. In R.J. Davidson, G.E. Schwarts & D. Shapiro (Eds), Consciousness and self-regulation. Advances in research and theory, Vol. 4, pp. 1-18. New York: Plenum Press.

Oakhill, J. V., Yuill, N., & Parkin, A. J. (1986). On the nature of the difference between skilled and less-skilled comprehenders. Journal of Research in Reading, 9, 80-91.

Paivio, A. (1971). Imagery and verbal processes. New York: Holt, Rinehart & Winston.

Paivio, A. (1986). Mental Representations: A dual coding approach. New York: Oxford University Press.

Paivio, A. (1988). Basic puzzles in imagery research. In M. Denis, J. Engelkamp & J. T. E. Richardson (eds), Cognitive and Neuropsychological Approaches to Mental Imagery, (pp.3-16). Dordrecht: Martinus Nijhoff Publishers, NATO ASI series.

Parr, W. V. (1992). Delayed matching-to-sample performance as a measure of human visuospatial working memory. Bulletin of the Psychonomic Society, 30, 369-372.

Pew, R. W. (1966). Acquisition of hierarchical control over the temporal organisation of a skill. Journal of Experimental Psychology, 71, 764-772.

Phillips, R. J. (1978). Recognition, recall and imagery of faces. In M. M. Gruneberg, P. E. Morris & R. N. Sykes (Eds.), Practical Aspects of Memory, pp.270-277. London: Academic Press.

Phillips, W. A. (1983). Short-term visual memory. Philosophical Transactions of the Royal Society of London B302, 295-309.

Phillips, W. A., & Christie, D. F. M. (1977a). Components of Visual Memory. Quarterly Journal 0f Experimental Psychology, 29, 117-133.

Phillips, W. A., & Christie, D. F. M. (1977b). Interference with visualisation. Quarterly Journal of Experimental Psychology, 29, 637-650.

Posner, M. I. (1967). Characteristics of visual and kinaesthetic memory codes. Journal of Experimental Psychology, 75, 103-107.

Posner, M. I. (1980). Orienting of attention: Seventh Bartlett Memorial Lecture. Quarterly Journal of Experimental Psychology, 32, 3-25.

Postman, L. (1975). Verbal learning and memory. Annual Review of Psychology, 26, 291-335.

Poulton, E. C. (1957). On prediction in skilled movements. Psychological Bulletin, 54, 467-478.

Quinn, J. G. (1988a). Interference effects in the visuo-spatial sketchpad. In M. Denis, J. Engelkamp, & J.T.E. Richardson (eds.), Cognitive and neuropsychological approaches to mental imagery, pp.181-189. Dordrecht: Martinus Nijhoff Publishers.

Quinn, J. G. (1988b). Movement and Movement Predictability in Visual Working Memory. In C. Cornoldi (ed.), Imagery & Cognition. Pre-proceedings of the Second International Workshop on Imagery and Cognition, University of Padua, Italy, 21-23rd September 1988, pp.361-372.

Quinn, J. G. (1990). Movement Interference in Visual Working Memory. In Images in Cognition: Proceedings of the Third European Workshop on Imagery and Cognition, pp.6-8. Aberdeen, Scotland, 15-18 August.

Quinn, J. G. (1991). Encoding and maintenance of information in visual working memory. In R. H. Logie & M. Denis (Eds.), Mental images in human cognition, pp.95-104. Amsterdam: Elsevier Publishers B.V.

Quinn, J. G. (1992). Complexity in Spatial processing. Paper presented to the International Workshop on Imagery and Motor Processes. University of Leicester, Leicester, England. 10-11th September.

Quinn, J. G. (1994). Towards a clarification of spatial processing. Quarterly Journal of Experimental Psychology, 47A, 465-480.

Quinn, J. G., & McConnell, J. (1994). The irrelevant picture effect in the visuo-spatial sketchpad. Paper presented at the International Conference on Working Memory, Cambridge, UK. 20-22 July.

Quinn, J. G., & Ralston, G. E. (1986). Movement and attention in visual working memory. Quarterly Journal of Experimental Psychology, 38A, 689-703.

Reber, A. S. (1985). The Penguin Dictionary of Psychology. London: The Penguin Group.

Reisberg, D., & Leak, S. (1987). Visual imagery and memory for appearance: Does Clark Gable or George C. Scott have bushier eyebrows? Canadian Journal of Psychology, 41, 521-526.

Reisberg, D., & Logie, R. H. (1993). The ins and outs of visual working memory: Overcoming the limits on learning from imagery. In M. J. Intons-Peterson, B. Roskos-Ewoldsen, & R. Anderson (Eds.), Imagery, creativity, and discovery: A cognitive approach, pp.39-76. Amsterdam: Elsevier.

Reisberg, D., Culver, C., Heuer, F. & Fischman, D. (1986). Visual memory: When imagery vividness makes a difference. Journal of Mental Imagery, 9, 67-86.

Reisberg, D., Rappaport, I. & O'Shaughnessy, M. (1984). Limits of working memory: The digit-digit span. Journal of Experimental Psychology: Learning, Memory & Cognition, 10, 203-221.

Richardson, A. (1977). The meaning and measurement of memory imagery. British Journal of Psychology, 68, 29-43.

Richardson, A. (1979). Dream recall frequency and vividness of visual imagery. Journal of Mental Imagery, 3, 65-72.

Richardson, J. T. E. (1988). Vividness and unvividness: Reliability, consistency, and validity of subjective imagery ratings. Journal of Mental Imagery, 12, 115-122.

Richardson, J. T. E. (1993). Commentary: Developing the model of working memory. In G. M. Davies & R. H. Logie (Eds.), Memory in everyday life, pp.219-230. Amsterdam: Elsevier Publishers B.V.

Rossi, J. S., & Fingeret, A. L. (1977). Individual difference in verbal and visual imagery abilities: Paired-associate recall as a function of stimulus and response correctness. Perceptual & Motor Skills, 44, 1043-1049.

Ruchkin, D. S., Johnson, R., Grafman, J., Canoune, H. & Ritter, W. (1992). Distinctions and similarities among working memory processes: An event-related potential study. Cognitive Brain Research, 1, 53-66.

Saariluoma, P. (1991). Visuo-spatial interference and apperception in chess. In R. H. Logie & M. Denis (Eds.), Mental images in human cognition. Amsterdam: Elsevier Publishers B.V.

Saffran, E. M., & Martin, N. (1990). Short-term memory impairment and sentence processing: a case study. In G. Vallar & T. Shallice (Eds), Neuropsychological impairments of short-term memory (pp.428-447). Cambridge: Cambridge University Press.

Saito, S. (1993). The disappearance of phonological similarity effect by complex rhythmic tapping. Psychologia, 36, 27-33.

Saito, S. (1994). What effect can rhythmic finger tapping have on the phonological similarity effect? Memory & Cognition, 22, 181-187.

Salame, P., & Baddeley, A. D. (1982). Disruption of short-term memory by unattended speech: implications for the structure of working memory. Journal of Verbal Learning and Verbal Behaviour, 21, 150-164.

Salmoni, A.W. (1989). Motor skill learning. In D. H. Holding (ed.), Human Skills, 2nd edition, (197-226). Chichester: John Wiley & Sons.

Salway, A. F. S. (1990). Working memory: Assessment of the visuo-spatial component and difficulty of laboratory tasks. In Images in Cognition: Proceedings of the 3rd European Workshop on Imagery and Cognition, pp.1-3. Aberdeen, Scotland. 15-18thAugust.

Salway, A. F. S. (1991). Random generation in the working memory dual-task paradigm. Unpublished PhD thesis, University of Aberdeen, Scotland, UK.

Schmidt, R. A. (1975). A schema theory of discrete motor skill leaning. Psychological Review, 82, 225-260.

Schneider, W., & Shiffrin R. M. (1977). Controlled and automatic human information processing I: Detection, search and attention. Psychological review, 84, 1-66.

Schneider, W., & Shiffrin, R. (1985). Categorisation (restructuring) and automatisation: Two separable factors. Psychological Review, 92, 424-428.

Shallice, T. (1982). Specific impairments of planning. Philosophical Transactions of the Royal Society, London B 298, 199-209.

Shallice, T. (1988). From neuropsychology to mental structure. Cambridge: Cambridge University Press.

Shallice, T., & Burgess, P. (1993). Supervisory control of action and thought selection. In A. D. Baddeley & L. Weiskrantz (eds.), Attention: selection, awareness, and control, A tribute to Donald Broadbent, pp.171-187. Oxford: Oxford University Press.

Shallice, T., & Warrington, E. K. (1970). Independent functioning of verbal memory stores: A neuropsychological study. Quarterly Journal of Experimental Psychology, 22, 261-273.

Shallice, T., Burgess, P., Schon, F., & Baxter, D. (1989). The origins of utilisation behaviour. Brain, 112, 1587-98.

Shallice, T., McLeod, P., & Lewis, K. (1985). Isolating cognitive modules with the dual-task paradigm: Are speech perception and production separate processes? Quarterly Journal of Experimental Psychology, 37A, 507-532.

Sheehan, P. W. (1967). A shortened form of Betts' Questionnaire Upon Mental Imagery. Journal of Clinical Psychology, 23, 386-389.

Sheehan, P. W., & Neisser, U. (1969). Some variables affecting the vividness of imagery in recall. British Journal of Psychology, 60, 71-80.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. Psychological Review, 84, 127-190.

Smith, J. D., Reisberg, D., & Wilson, M. (1992). Subvocalisation and auditory imagery: Interactions between the inner ear and inner voice. In D. Reisberg (ed.), Auditory imagery, pp.95-119. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Smyth, M. M., & Pelky, P. L. (1992). Short-term retention of spatial information. British Journal of Psychology, 83, 359-374.

Smyth, M. M., & Pendleton, L. R. (1989). Working Memory for Movements. Quarterly Journal of Experimental Psychology, 41A, 235-250.

Smyth, M. M., & Pendleton, L. R. (1990). Space and movement in working memory. Quarterly Journal of Experimental Psychology, 42A, 291-304.

Smyth, M. M., & Scholey, K. A. (1992). Determining Spatial Span: The role of movement time and articulation rate. Quarterly Journal of Experimental Psychology, 45A, 479-501.

Smyth, M. M., & Scholey, K. A. (1994a). Interference in immediate spatial memory. Memory & Cognition, 22, 1-13.

Smyth, M. M., & Scholey, K. A. (1994b). Characteristics of Spatial Memory Span: Is there an analogy to the word length effect, based on movement time? Quarterly Journal of Experimental Psychology, 47A, 91-117.

Smyth, M. M., & Wing, A. M. (1984). Movement, Action, and Skill. In M. M. Smyth & Wing, A. M. (eds), The Psychology of Human Movement, pp.1-15. New York: Academic Press.

Smyth, M. M., Collins, A. F., Morris, P. E., & Levy, P. (1994). Cognition in Action, 2nd edn. Hove, UK: Lawrence Erlbaum Associates.

Smyth, M. M., Pearson, N. A., & Pendleton, L. R. (1988). Movement and working memory: Patterns and positions in space. Quarterly Journal of Experimental Psychology, 40A, 497-514.

Spinnler, H., Della Sala, S., Bandera, R., & Baddeley, A. D. (1988). Dementia, ageing, and the structure of human memory. Cognitive Neuropsychology, 5, 193-211.

Swann, W. B., & Miller, L. C. (1982). Why never forgetting a face matters---visual imagery and memory. Journal of Personality and Social Psychology, 43, 475-480.

Toms, M., Morris, N., & Foley, P. (1994). Characteristics of visual interference with visuospatial working memory. British Journal of Psychology, 85, 131-144.

Tulving, E. (1966). Subjective organisation and effects of repetition in multi-trial free-recall learning. Journal of Verbal Learning & Verbal Behaviour, 5, 193-197.

Tzeng, O. J. (1973). Positive recency effect in delayed free recall. Journal of Verbal Learning & Verbal Behaviour, 12, 436-439.

Vallar, G. & Baddeley, A. D. (1982). Short-term forgetting and the articulatory loop. Quarterly Journal of Experimental Psychology, 34, 53-60.

Vallar, G., & Baddeley, A. D. (1984). Fractionation of working memory: Neuropsychological evidence for a phonological short-term store. Journal of Verbal Learning and Verbal Behaviour, 23, 151-161.

Vallar, G., & Baddeley, A. D. (1987). Phonological short-term store and sentence processing. Cognitive Neuropsychology, 4, 417-438.

Van der Linden, M., Bredart, S., & Beerten, A. (1994). Age-related differences in updating working memory. British Journal of Psychology, 85, 145-152.

Van der Linden, M., Coyette, F., & Seron, X. (1992). Selective impairment of the 'central executive' component of working memory: A single case study. Cognitive Neuropsychology, 9, 301-326.

Vecchi, T., Monticellai, M. & Cornoldi, C. (1995). Visuo-spatial working memory: Structures and variables affecting a capacity measure. Neuropsychologia, 33, 11, 1549-1564.

Wagenaar, W. A. (1972). Generation of random sequences by human subjects: A critical survey of the literature. Psychological Bulletin, 77, 65-72.

Walker, P., Hitch, G. J. & Duroe, S. (1993). The effect of visual similarity on short-term memory for spatial location: Implications for the capacity of visual short-term memory. Acta Psychologica, 83, 203-224.

Wallace, B. (1991). Imaging ability and performance on a proofreading task. Journal of Mental Imagery, 15, 177-188.

Wang, P. P., & Bellugi, U. (1994). Evidence from two genetic syndromes for a dissociation between verbal and visuo-spatial short-term memory. Journal of Clinical and Experimental Neuropsychology, 16, 317-322.

Waugh, N. C., & Norman, D. A. (1965). Primary memory. Psychological Review, 72, 89-104.

White, K., Sheehan, P. W., & Ashton, R. (1977). Imagery assessment: A survey of self-report measures. Journal of Mental Imagery, 1, 145-170.

Wickens, C. D. (1984). Processing resources in attention. In R. Parasuraman & D. R. Davies (eds.), Varieties of attention (pp.63-102). New York: Academic press.

Wilson, J. T. L., Scott, J. H., & Power, K. G. (1987). Developmental differences in the span of visual memory for pattern. British Journal of Developmental Psychology, 5, 249-255.

Appendix 1.1.

Vividness of Movement Imagery Questionnaire

Subject Name:

Subject Number:

Date:

Movement imagery refers to the ability to imagine a movement. The aim of this test is to determine the vividness of your movement imagery. The items of the test are designed to bring certain images to your mind. You are asked to rate the vividness of each item by reference to the 5-point scale. After each item, write the appropriate number in the box provided. The first box is for an image obtained watching somebody else and the second box is for an image obtained doing it yourself. Try to do each item separately, independently of how you may have done other items. Complete all items obtained watching somebody and then return to the beginning of the questionnaire and rate the image obtained doing it yourself. The two ratings for a given item may not in all cases be the same. For all items please have your eyes CLOSED.

Rating Scale.

The image aroused by each item might be:

Perfectly clear and as vivid as normal vision	.....	Rating 1
Clear and reasonably vivid	.....	Rating 2
Moderately clear and vivid	.....	Rating 3
Vague and dim	.....	Rating 4
No image at all, you only "know" that you are thinking of an object	.....	Rating 5

Think of each of the following acts. Classify the images according to the degree of clearness and vividness as shown on the RATING SCALE.

Item	Rating Watching some body else	Rating Doing it yourself
1. Standing	( )	( )

2. Walking	( )	( )
3. Running	( )	( )
4. Jumping	( )	( )
5. Reaching for something on tiptoe	( )	( )
6. Drawing a circle on paper	( )	( )
7. Kicking a stone	( )	( )
8. Bending to pick up a coin	( )	( )
9. Falling forwards	( )	( )
10. Running upstairs	( )	( )
11. Jumping sideways	( )	( )
12. Slipping over backwards	( )	( )
13. Catching a ball with two hands	( )	( )
14. Throwing a stone into water.	( )	( )
15. Kicking a ball in the air.	( )	( )
16. Hitting a ball along the ground.	( )	( )
17. Running downhill.	( )	( )
18. Climbing over a high wall.	( )	( )
19. Sliding on ice.	( )	( )
20. Riding a bike.	( )	( )
21. Jumping into water.	( )	( )
22. Swinging on a rope.	( )	( )
23. Balancing on one leg.	( )	( )
24. Jumping off a high wall.	( )	( )

Appendix 1.2.

TOTAL SCORES

(a) Eyes open =
(b) Eyes closed =
Total (a+b) =

VIVIDNESS OF VISUAL IMAGERY QUESTIONNAIRE

Name:

Age:

Male or Female:

Occupation (if student, then give course of study and stage reached):

Visual imagery refers to the ability to visualize, that is, the ability to form mental pictures, or to "see in the mind's eye". Marked individual differences have been found in the strength and clarity of reported visual imagery and these differences are of considerable psychological interest.

The aim of this test is to determine the vividness of your visual imagery The items of the test will possibly bring certain images to your mind. You are asked to rate the vividness of each image by reference to the 5-point scale given below. For example, if your image is "vague and dim" then give it a rating of 4. After each item write the appropriate number in the box provided. The first box is for an image obtained with your eyes open and the second box is for an image obtained with your eyes closed. Before you turn to the items on the next page, familiarize yourself with the different categories on the rating scale. Throughout the test, refer to the rating scale when judging the vividness of each image. Try to do each item separately, independent of how you may have done other items.

Complete all items for images obtained with the eyes open and then return to the beginning of the questionnaire and rate the image obtained for each item with your eyes closed. Try and give your "eyes closed" rating independently of the "eyes open" rating. The two ratings for a given item may not in all cases be the same.

Rating Scale

The image aroused by an item might be:

Perfectly clear and as vivid as normal vision	.....	Rating 1
Clear and reasonably vivid	.....	Rating 2
Moderately clear and vivid	.....	Rating 3
Vague and dim	.....	Rating 4
No image at all, you only "know" that you are thinking of an object	.....	Rating 5

In answering items 1 to 4, think of some relative or friend whom you frequently see (but who is not with You at present) and consider carefully the picture that comes before your mind's eye.

Item	Rating with eyes Open	Rating with eyes Closed
1) The exact contour of face, head shoulders and body.		
2) Characteristic poses of head, attitudes of body etc.		
3) The precise carriage, length of step, etc. in walking.		
4) The different colours worn in some familiar clothes.		

Visualize the rising sun. Consider carefully the picture that comes before your mind's eye.

Item	Rating with eyes Open	Rating with eyes Closed
5) The sun is rising above the horizon into a hazy sky.		
6) The sky clears and surrounds the sun with blueness.		
7) Clouds. A storm blows up, with flashes of lightning.		
8) A rainbow appears.		

Rating Scale

The image aroused by an item might be:

Perfectly clear and as vivid as normal vision	.....	Rating 1
Clear and reasonably vivid	.....	Rating 2
Moderately clear and vivid	.....	Rating 3
Vague and dim	.....	Rating 4
No image at all, you only "know" that you are thinking of an object	.....	Rating 5

Think of the front of a shop which you often go to. Consider the picture that comes before your mind's eye.

Item	Rating with eyes Open	Rating with eyes Closed
9) The overall Appearance of the shop from the opposite side of the road.		
10) A window display including colours, shapes and details of individual items for sale.		
11) You are near the entrance. The colour, shape 'and details of the door.		
12) You enter the shop and go to the counter. The counter assistant serves you. Money changes hands.		

Finally, think of a country scene which involves trees, mountains and a lake. Consider the picture that comes before your mind's eye.

Item	Rating with eyes Open	Rating with eyes Closed
13) The contours of the landscape		
14) The colour and shape of the trees		
15) The colour ind shape of the lake		
16) A strong wind blows on the trees and on the lake causing waves		

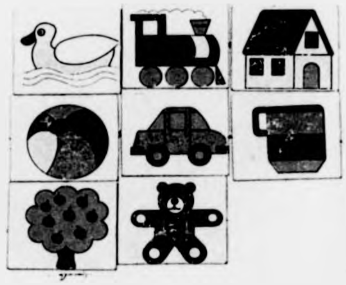
Rating Scale

The image aroused by an item might be:

Perfectly clear and as vivid as normal vision	.....	Rating 1
Clear and reasonably vivid	.....	Rating 2
Moderately clear and vivid	.....	Rating 3
Vague and dim	.....	Rating 4
No image at all, you only "know" that you are thinking of an object	.....	Rating 5

Appendix 2.1

Experiment I. Illustrations of the material & experimental set-ups



The 8 cards containing (coloured) pictures of the 8 objects used in the PB condition.

Experiment 1-a. The subject verbally encoding the task by listening to the Brooks visuo-spatial sentences.

Experiment 1-b. The subject visually decoding the SB task by placing 8 cards representing the digits on a real matrix.

Experiment 1-c. The subject visually encoding the PB task by watching 8 displays of the matrix on a portable screen.

Experiment 1-d. The experimental set-up with the subject visually encoding the SB task by watching 8 displays of the matrix on a portable screen.

Appendix 2.2.

The Matrix sequences used for the SB condition in Experiment I.

Sequence # 1:
In the starting square put a 1.
In the next square to the left put a 2.
In the next square up put a 3.
In the next square to the right put a 4.
In the next square to the right put a 5.
In the next square down put a 6.
In the next square down put a 7.
In the next square to the right put an 8.

Sequence # 2:
In the starting square put a 1.
In the next square up put a 2.
============ to the left put a 3.
============ down put a 4.
============ down put a 5.
============ to the right put a 6.
============ down put a 7.
============ to the left put an 8.

Sequence # 3:
In the starting square put a 1.
In the next square down put a 2.
=============to the right put a 3.
=============down put a 4.
=============to the right put a 5.
=============up put a 6.
=============up put a 7.
=============to the left put an 8.

Sequence # 4:
In the starting square put a 1.
In the next square to the right put a 2.
=============down put a 3.
=============to the left put a 4.
=============down put a 5.
=============to the left put a 6.
=============up put a 7.
=============up put an 8.

Sequence # 5:
In the starting square put a 1.
In the next square to the left put a 2.
=============down put a 3.
=============to the right put a 4.
=============down put a 5.
=============to the right put a 6.
=============up put a 7.
=============to the right put an 8.

Sequence # 6:
In the starting square put a 1.
In the next square up put a 2.
=============to the right put a 3.
=============to the right put a 4.
=============down put a 5.
=============to the left put a 6.
=============down put a 7.
=============to the left put an 8.

Sequence # 7:
In the starting square put a 1.
In the next square down put a 2.
============ to the left put a 3.
============ down put a 4.
============ to the right put a 5.
============ to the right put a 6.
============ up put a 7.
============ to the right put an 8.

Sequence # 8:
In the starting square put a 1.
In the next square to the right put a 2.
=============up put a 3.
=============to the right put a 4.
=============down put a 5.
=============down put a 6.
=============to the left put a 7.
=============down put an 8.

<u>The Matrix sequences used for the PB condition in Experiment I.</u>

The digits 1-8 were replaced by the eight objects: Duck , Train , House , Ball , Car , Cup , Tree , and Bear.

Sequence # 1:
In the starting square put a Duck.
In the next square to the left put a Train.
=============up put a House.
=============to the right put a Ball.
=============to the right put a Car.
=============down put a Cup.
=============down put a Tree.
=============to the right put a Bear.

Sequence # 2:
In the starting square put a Duck.
In the next square up put a Train.
=============to the left put a House
=============down put a Ball.
=============down put a Car.
=============to the right put a Cup.
=============down put a Tree.
=============to the left put a Bear.

Sequence # 3:
In the starting square put a Duck.
In the next square down put a Train.
=============to the right put a House.
=============down put a Ball.
=============to the right put a Car.
=============up put a Cup.
=============up put a Tree.
=============to the left put a Bear.

Sequence # 4:
In the starting square put a Duck.
In the next square to the right put a Train.
=============down put a House.
=============to the left put a Ball.
=============down put a Car.
=============to the left put a Cup.
=============up put a Tree.
=============up put a Bear.

Sequence no 5:
In the starting square put a Duck.
In the next square to the left put a Train.
=============down put a House.
=============to the right put a Ball.
=============down put a Car.
=============to the right put a Cup.
=============up put a Tree.
=============to the right put a Bear.

Sequence # 6:
In the starting square put a Duck.
In the next square up put a Train.
=============to the right put a House.
=============to the right put a Ball.
=============down put a Car.
=============to the left put a Cup.
=============down put a Tree.
=============to the left put a Bear.

Sequence # 7:
In the starting square put a Duck.
In the next square down put a Train.
=============to the left put a House.
=============down put a Ball.
=============to the right put a Car.
=============to the right put a Cup.
=============up put a Tree.
=============to the right put a Bear.

Sequence # 8:
In the starting square put a Duck.
In the next square to the right put a Train.
=============up put a House.
=============to the right put a Ball.
=============down put a Car.
=============down put a Cup.
=============to the left put a Tree.
================ down put a Bear.

Appendix 2.3

Verbal Instructions for Experiment 1-a

1) For the SB condition:

After the initial introduction of the experiment and the task to the subject, show a 4x4 matrix with the starting square marked. Then say:
You will listen to a set of 8 sentences describing the locations of the digits 1-8 in relation to one another within the matrix. The first digit will always be in the same marked square.

Your task is to repeat the sentences word by word after the presentation of all of the 8 sentences. You have to attempt to remember the sentences by forming a mental image of the digits relative to one another within the matrix. You could then use that image to reconstruct the sentences at recall.
Let us start off with 2 practice trials.

2) For the PB condition:

After the initial introduction of the experiment and the task to the subject, show a 4x4 matrix with the starting square marked and also show the pictures of the 8 objects. Give the subject training to memorise the objects in the specified order. Then say:
You will listen to a set of 8 sentences describing the locations of these 8 objects in relation to one another within the squares of the matrix. The first object will always be in the same marked square.

Your task is to repeat the sentences word by word after the presentation of all of the 8 sentences. You have to attempt to remember the sentences by forming a mental image of the objects relative to one another within the matrix. You could then use that image to reconstruct the sentences at recall.
Let us start off with 2 practice trials.

Instructions for Experiment 1-b

1) For the SB condition

After the initial introduction of the experiment & the task to the subject, show a 4x4 matrix with the starting square marked and the cards of the 8 digits. Then say:
You will listen to a set of 8 sentences which describe the locations of those digits in relation to one another within the matrix. The first digit will always be in the same marked square.

After you have listened to all of the 8 sentences, your task will be to place the digits on the matrix in the exact locations indicated by the sentences. You could start by placing any digit you choose but always remember that it is very important to always try to place the digits in the exact squares indicated by the sentences.
You have to attempt to remember the items by forming a mental image of the digits relative to one another within the matrix. You could then use that image to reconstruct the items at recall.
Let us start off with 2 practice trials:

2) For the PB condition

After the initial introduction of the experiment & the task to the subject, show the 4x4 matrix with the starting square marked and also show the pictures of the 8 objects. Give the subject training to memorise the objects in the specified order. Then say:
You will listen to a set of 8 sentences that describe the locations of these 8 objects in relation to one another within the matrix. The first object will always be in the same marked square.

After you have listened to all of the 8 sentences, your task will be to place the objects on the matrix in the exact locations indicated by the sentences. You could start by placing any object you choose but always remember that it is very important to always try to place the objects in the exact squares indicated by the sentences.
You have to attempt to remember the items by forming a mental image of the objects relative to one another within the matrix. You could then use that image to reconstruct the items at recall.
Let us start off with 2 practice trials.

Instructions for Experiment 1-c

1) For the SB condition

After the initial introduction of the experiment & the task to the subject, show a 4x4 matrix with the starting square marked and the cards of the 8 digits. Then say:
You will see a set of 8 slides showing the locations of these 8 digits in relation to one another within the squares of the matrix. The first digit will always be in the same starting square.
Your task is to describe the locations of each of these digits after the presentation of all of the 8 slides.

You have to attempt to remember the locations by forming a mental image of the digits relative to one another within the matrix. You could then use that image at recall to construct sentences with the following structure:

In the starting square put a 1.
In the next square (up, down, to the left, or to the right) put a 2.
In the next square (up, down, to the left, or to the right) put a 3.
And so on until you describe the location of the last digit. There is no limit on response time. Let us start off with 2 practice.

2) For the PB condition

After the initial introduction of the experiment & the task to the subject, show a 4x4 matrix with the starting square marked and also show the pictures of the 8 objects. Give the subject training to memorise the objects in the specified order. Then say:
You will see a set of 8 slides showing the locations of these 8 objects in relation to one another within the squares of the matrix. The first object will always be in the same starting square.

Your task is to describe the locations of each of these objects after the presentation of all of the 8 slides.
You have to attempt to remember the locations by forming a mental image of the objects relative to one another within the matrix. You could then use that image at recall to construct sentences with the following structure:

In the starting square put a Duck.
In the next square (up, down, to the left, or to the right) put a Train.
In the next square (up, down, to the left, or to the right) put a House.
And so on until you describe the location of the last object. There is no limit on response time. Let us start off with 2 practice.

Instructions for Experiment 1-d

1) For the SB condition

After the initial introduction of the experiment & the task to the subject, show a 4x4 matrix with the starting square marked and the cards of the 8 digits. Then say:
You will see a set of 8 slides showing the locations of these 8 digits in relation to one another within the squares of the matrix. The first digit will always be in the same starting square.

After you have seen all of the 8 slides, your task will be to place the digits on the matrix in the exact locations shown by the slides. You could start by placing any digit you choose but always remember that it is very important to always try to place the digits in the exact squares as indicated by each set of 8 slides.
You have to attempt to remember the items by forming a mental image of the digits relative to one another within the matrix. You could then use that image to reconstruct the items at recall.
Let us start off with 2 practice trials:

2) For the PB condition

After the initial introduction of the experiment & the task to the subject, show a 4x4 matrix with the starting square marked and also show the pictures of the 8 objects. Give the subject training to memorise the objects in the specified order. Then say:
You will see a set of 8 slides showing the locations of these 8 objects in relation to one another within the squares of the matrix. The first object will always be in the same starting square.

After you have seen to all of the 8 slides, your task will be to place the objects on the matrix in the exact locations shown by the slides. You could start by placing any object you choose but always remember that it is very important to always try to place the objects in the exact squares indicated by the slides.
You have to attempt to remember the items by forming a mental image of the objects relative to one another within the matrix. You could then use that image to reconstruct the items at recall.
Let us start off with 2 practice trials.

Appendix 3.1

The additional 8 Matrix sequences used in Experiment II:

Sequence 9

In the starting square put a 1.
In the next square to the right put a 2.
==============to the right put a 3.
==============down put a 4.
==============to the left put a 5.
==============to the left put a 6.
==============down put a 7.
==============to the right put an 8.

Sequence 10

In the starting square put a 1.
In the next square up put a 2.
==============to the right put a 3.
==============down put a 4.
==============down put a 5.
==============to the left put a 6.
==============to the left put a 7.
==============down put an 8.

Sequence 11

In the starting square put a 1.
In the next square down put a 2.
==============down put a 3.
==============to the right put a 4.
==============to the right put a 5.
==============up put a 6.
==============to the left put a 7.
==============up put an 8.

Sequence 12

In the starting square put a 1.
In the next square to the left put a 2.
==============down put a 3.
==============to the right put a 4.
==============down put a 5.
==============to the right put a 6.
==============to the right put a 7.
==============up put an 8.

Sequence 13

In the starting square put a 1.
In the next square to the right put a 2.
==============to the right put a 3.
==============down put a 4.
==============to the left put a 5.
==============down put a 6.
==============to the left put a 7.
==============up put an 8.

Sequence 14

In the starting square put a 1.
In the next square up put a 2.
==============to the right put a 3.
==============down put a 4.
==============down put a 5.
==============to the right put a 6.
==============down put a 7.
==============to the left put an 8.

Sequence 15

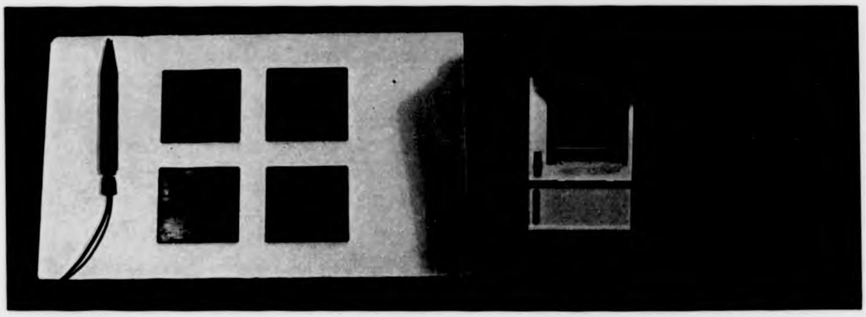
In the starting square put a 1.
In the next square to the left put a 2.
==============down put a 3.
==============to the right put a 4.
==============to the right put a 5.
==============down put a 6.
==============to the right put a 7.
==============up put an 8.

Sequence 16

In the starting square put a 1.
In the next square down put a 2.
==============down put a 3.
==============to the right put a 4.
==============up put a 5.
==============up put a 6.
==============to the right put a 7.
============== up put an 8.

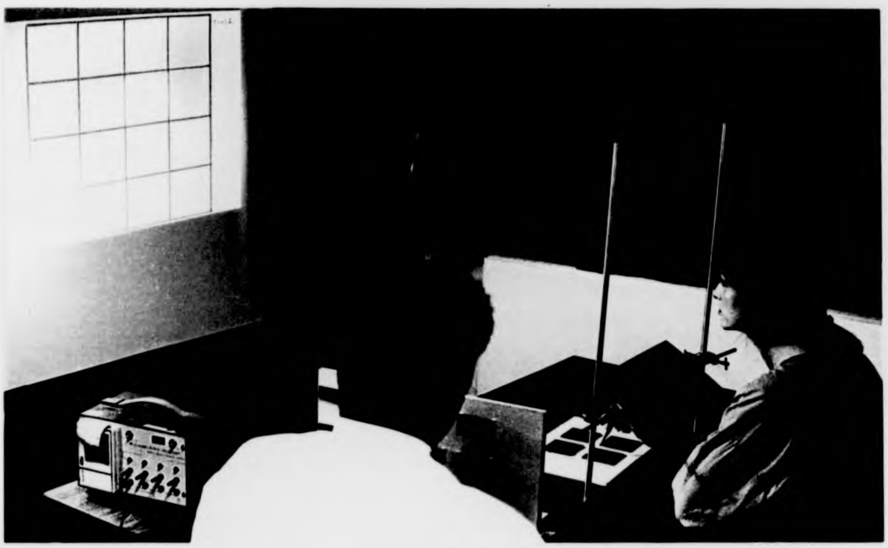
Appendix 3.2

Experiment II. Illustrations of the material & experimental set-ups



The tapping apparatus: 4 metal plates on a board, Stylus, and the 4-Channel Event Recorder.

Experiment II. The experimental set-up with the subject verbally encoding the Brooks task whilst tapping in time to the auditory signal.



Experiment II. The subject visually encoding the Brooks task whilst tapping in time to the auditory signal.

Appendix 3.3

The HyperCard script for emitting the regular auditory signals used in the spatial and simple tapping conditions:

```
on mouseUp
  repeat 600
    wait 60 ticks
    beep
  end repeat
end mouseUp
```

The HyperCard script for emitting the rhythmic auditory signals used in the rhythmic tapping condition:

```
on mouseUp
  repeat 600
    wait 25 ticks
    beep
    wait 60 ticks
    beep
    wait 100 ticks
    beep
    wait 55 ticks
    beep
  end repeat
end mouseUp
```

Appendix 3.4.

Verbal instructions for Experiment 2-a

1) For verbal presentation:

a) No interference condition:

After the initial introduction of the experiment & the matrix task to the subject, show a 4x4 matrix with the starting square marked. Then say:
You will listen to a set of 8 sentences describing the locations of the digits 1-8 in relation to one another within the squares of the matrix. The first digit will always be in the same marked square.
Your task is to repeat the sentences word by word after the presentation of all of the 8 sentences.

You have to attempt to remember the sentences by forming a mental image of the digits relative to one another within the matrix. You could then use that image to reconstruct the sentences at recall. There is no limit on response time. Let us start off with some practice.

b) Simple tapping:

.... Also during the presentation of the 8 sentences, I would like you to tap, using the stylus, on this metal plate.
You should tap on this plate every time you hear the auditory signal. You should stop tapping after the last sentence has been played. There will be no tapping during recall.
Demonstrate this tapping task to the subject and give some training. Then: Let us start off with a practice trial.

c) Spatial tapping:

.... Also during the presentation of the 8 sentences, I would like you to tap, using the stylus, round these 4 metal plates in turn in a clockwise direction.
You should tap each plate in its turn every time you hear the auditory signal. You should stop tapping after the last sentence has been played. There will be no tapping during recall.
Demonstrate the spatial tapping task to the subject. Give the subject some training on this tapping task and encourage them to hit the plates accurately in the indicated sequence. Then: Let us start off with a practice trial.

d) Rhythmic tapping:

.... Also during the presentation of the 8 sentences, I would like you to tap, using the stylus, on this metal plate.

You should tap on this plate every time you hear the auditory signal (beep). The intervals between the signals will be variable. You must try to keep up the tapping with the signals. You should stop tapping after the last sentence has been played. There will be no tapping during recall.
Demonstrate this tapping task to the subject and give some training. Then: Let us start off with a practice trial.

2) For visual presentation:

a) No interference condition:

After the initial introduction of the experiment & the matrix task to the subject, show a 4x4 matrix with the starting square marked. Then say:
You will see a set of 8 slides showing the locations of the digits 1-8 in relation to one another within the squares of the matrix. The first digit will always be in the same starting square.
Your task is to describe the locations of each of these digits after presentation of all of the 8 slides. You have to attempt to remember the locations by forming a mental image of the digits relative to one another within the matrix. You could then use that image at recall to construct sentences with the following structure:

In the starting square put a 1.
In the next square (up, down, to the left, or to the right) put a 2.
In the next square (up, down, to the left, or to the right) put a 3.
And so on until you describe the location of the last digit. There is no limit on response time. Let us start off with some practice.

b) Simple tapping:

......Also, during presentation of the 8 slides, I would like you to tap, using the stylus, on this metal plate. You should tap on this plate every time you hear the auditory signal. You should stop tapping after the last slide has been displayed. There will be no tapping during recall.
Demonstrate this tapping task to the subject and give some training. Then: Let us start off with a practice trial.

c) Spatial tapping:

......Also, during presentation of the 8 slides, I would like you to tap, using the stylus, round these 4 metal plates in turn in a clockwise direction. You should tap each plate in its turn every time you hear the auditory signal.
You should stop tapping after the last slide has been displayed. There will be no tapping during recall.
Demonstrate the spatial tapping task to the subject. Give the subject some training on this tapping task and encourage them to hit the plates accurately in the indicated sequence. Then: Let us start off with a practice trial.

d) Rhythmic tapping:

.... Also during the presentation of the 8 slides, I would like you to tap, using the stylus, on this metal plate.
You should tap on this plate every time you hear the auditory signal (beep). The intervals between the signals will be variable. You must try to keep up the tapping with the signals. You should stop tapping after the last slide has been displayed. There will be no tapping during recall.
Demonstrate this tapping task to the subject and give some training. Then: Let us start off with a practice trial.

Instructions for Experiment 2-b

1) For verbal presentation:

Introduction of the matrix task:
Same as in Experiment 2-a (the no interference condition).

a) Spatial tapping

........Also during presentation of the 8 sentences, I would like you to tap, using the stylus, round these 4 metal plates in turn in a clockwise direction.
You must tap each plate in its turn every time you hear the auditory signal. You must try not to miss any signal. Your tapping will be recorded by this machine.
Also, always remember that your task is to perform the two tasks simultaneously and you must treat the two tasks equally by not concentrating on one task more than the other (remind the subject of these instructions in case of any notable noncompliance)

You should stop tapping after the last sentence has been played. There will be no tapping during recall.
Demonstrate the tapping task to the subject and give some training on this tapping task and encourage them to hit the plates accurately in the indicated sequence. Then: Let us start off with a practice trial.

b) Rhythmic tapping

........Also during presentation of the 8 sentences, I would like you to tap, using the stylus, on this metal plate. You must tap on this plate every time you hear the auditory signal. The intervals between the signals are variable and you must keep up the tapping with the signal. You must try not to miss any signal. Your tapping will be recorded by this machine.

Also, always remember that your task is to perform the two tasks simultaneously and you must treat the two tasks equally by not concentrating on one task more than the other (remind the subject of these instructions in case of any notable noncompliance)

You should stop tapping after the last sentence has been played. There will be no tapping during recall.
Demonstrate the tapping task to the subject and give some training. Then: Let us start off with a practice trial.

2) For visual presentation

Introduction of the matrix task:
Same as in Experiment 2-a (the no interference condition).

a) Spatial tapping

........Also during presentation of the 8 slides, I would like you to tap, using the stylus, round these 4 metal plates in turn in a clockwise direction.
You must tap each plate in its turn every time you hear the auditory signal. You must try not to miss any signal. Your tapping will be recorded by this machine.
Also, always remember that your task is to perform the two tasks simultaneously and you must treat the two tasks equally by not concentrating on one task more than the other (remind the subject of these instructions in case of any notable noncompliance)
You should stop tapping after the last slide has been displayed. There will be no tapping during recall.
Demonstrate the tapping task to the subject and give some training on this tapping task and encourage them to hit the plates accurately in the indicated sequence. Then: Let us start off with a practice trial.

b) Rhythmic tapping

........Also during presentation of the 8 slides, I would like you to tap, using the stylus, on this metal plate. You must tap on this plate every time you hear the auditory signal. The intervals between the signals are variable and you must keep up the tapping with the signal. You must try not to miss any signal. Your tapping will be recorded by this machine.
Also, always remember that your task is to perform the two tasks simultaneously and you must treat the two tasks equally by not concentrating on one task more than the other (remind the subject of these instructions in case of any notable noncompliance)
You should stop tapping after the last slide has been displayed. There will be no tapping during recall.
Demonstrate the tapping task to the subject and give some training. Then: Let us start off with a practice trial.

Appendix 4.1.

The script for the HyperCard button (Test 1) to present the first 'shortened' Brooks test in Experiment 3-c:

```
on mouseUp
  wait 150 ticks*
  go to card 1
  wait 150 ticks
  go to card 2
  wait 150 ticks
  go to card 3
  wait 150 ticks
  go to card 4
  wait 150 ticks
  go to card 5
  wait 150 ticks
  go to card 6
  wait 150 ticks
  go to card 7
  wait 150 ticks
  go to card 8
  wait 150 ticks
  go to card 9
end mouseUp
```

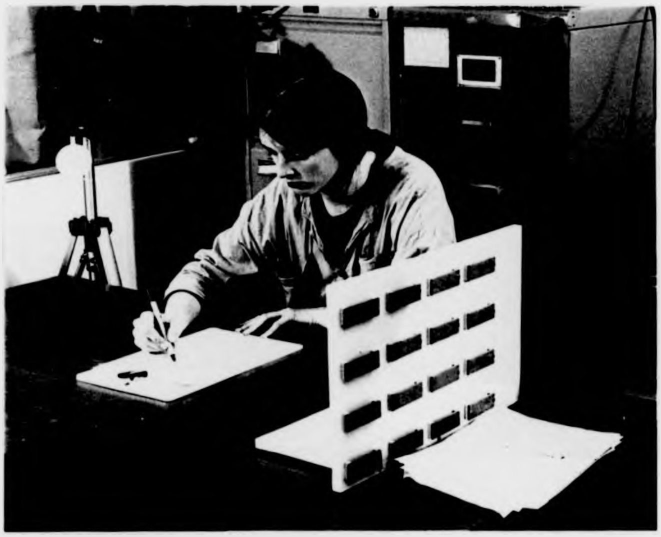
The script for the HyperCard button (Test 2) to present the second 'shortened' Brooks test in Experiment 3-c:

```
on mouseUp
  wait 150 ticks
  go to card 11
  wait 150 ticks
  go to card 12
  wait 150 ticks
  go to card 13
  wait 150 ticks
  go to card 14
  wait 150 ticks
  go to card 15
  wait 150 ticks
  go to card 16
  wait 150 ticks
  go to card 17
  wait 150 ticks
  go to card 18
  wait 150 ticks
  go to card 19
end mouseUp
```

*A tick in hyperCard equals 1/60 of a second. Hence, 150 ticks equal 2.5 seconds.

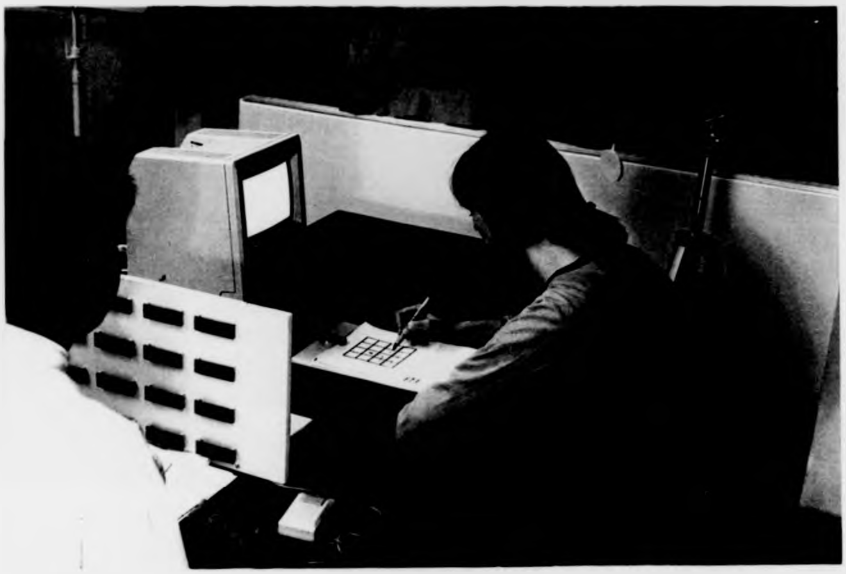
Appendix 4.2

Experiment III. Illustrations of the experimental set-ups



The experimental set-up for Condition 2 with the subject visually decoding the task by drawing a line on a real matrix.

The subject visually encoding the task in Condition 3 by watching a set of 8 displays of the matrix on a computer screen.



The experimental set-up in Condition 4, Experiment III, with the subject visually decoding the task by drawing a line on a real matrix.

Appendix 4.3.

Verbal Instructions for Experiment III

1) Instructions for Condition 1:

After the initial introduction of the experiment and the matrix task to the subject, show a 4x4 matrix with the starting square marked. Then say:
You will listen to a set of 8 short statements comprising spatial directions (starting square, up, left etc.) which describe a path around the squares of the matrix. The path will always begin from the same starting square (give an example of sequence of statements).

Your task is to repeat these short statements after the presentation of all of the 8 statements. You have to attempt to remember the statements by forming a mental image of the direction of the path within the squares of the matrix. You could then use that image at recall to help you reconstruct the 8 statements.
There is no limit on response-time. You should indicate that you have finished recall by saying the word 'finished' after recalling the last item.
Let us start off with 2 practice trials.

2) Instructions for Condition 2:

After the initial introduction of the experiment and the matrix task to the subject, show a 4x4 matrix with the starting square marked. Then say:
You will listen to a set of 8 short statements comprising spatial directions (starting square, up, left etc.) which describe a path around the squares of the matrix. The path will always begin from the same starting square (give an example of sequence of statements).

After you have listened to all of the 8 statements, you will be presented with a 4x4 matrix and your task will be to draw a line on the matrix representing your mental image of the path which has been described.

You have to attempt to remember the path by forming a mental image of the directions given in the 8 statements. You could then use that image to help you recall the path. There is no limit on response-time.
Let us start off with 2 practice trials.

3) Instructions for Condition 3:

After the initial introduction of the experiment and the matrix task to the subject, show a 4x4 matrix with the starting square marked. Then say:
You will see a set of 8 displays of the matrix on the computer screen that show a path around the squares of the matrix. The path will always begin from the same starting square (explain).
After you have seen all of the 8 displays, your task will be to verbally describe the direction of the path.

You have to attempt to remember the path by forming a mental image of the direction of the path within the matrix. You could then use that image to help you recall the path by constructing statements with the following structure:
Starting square, Up, Left, Down... and so on until the 8th square at which the path stopped has been described. You should say the word 'finished' when you have finished recalling. There is no limit on response-time.
Let us start off with 2 practice trials.

4) Instructions for Condition 4:

After the initial introduction of the experiment and the matrix task to the subject, show a 4x4 matrix with the starting square marked. Then say:
You will see a set of 8 displays of the matrix on the computer screen that show a path around the squares of the matrix. The path will always begin from the same starting square (explain).

After you have seen all of the 8 displays, you will be presented with a 4x4 matrix and your task will be to draw a line on the matrix representing your mental image of the path which has been shown.

You have to attempt to remember the path by forming a mental image of the direction of the path within the matrix. You could then use that image to help you recall the path. There is no limit on response-time.
Let us start off with 2 practice trials.

Appendix 4.4.

Examples of Subjects' reports in Experiment III

Condition 1

"Easy to visualise the first few items then it becomes hard, you can't visualise the grid itself,only parts of it with a pattern of squares that stands out, it is easier to visualise when I close my eyes";

"I imagine the squares and follow the pattern that was being created, it is hard to keep the picture specially at the end because the pattern gets hazy and you don't clearly 'see it'";

"It is difficult, hard to imagine the whole grid, I form a line within the squares but I keep losing it specially the last items, I run out of span and lose track, I might have done better if I just memorised the words";

"I was imagining the matrix while moving my head with the directions and forming a glowing trail (a line), the end of the line fades and I need to get back to the starting point, it is important that I recall the 'line' quickly before it disappears, it is good there were no more than 8 items because that is the maximum I can handle";

"It is hard because there was no easy or recognisable pattern, I had a picture of the whole grid with a pattern inside, last items are hard because the span is full and the end of the pattern is vague, I mainly relied on mental imagery but sometimes I backed it up with memorising the words, the mental image is very important";

"It is hard, I lose parts of the 'picture' when I try to recall the items verbally, it is difficult to maintain the image during recall because it just starts to disappears, I visualise the starting square and then a line that starts from there and goes in various directions and then I visualise where it ends, I sometimes visualise the items in pairs using the line all the time, it is easy to remember the first items because I 'saw' them in my mind the most but the end of the line tends to disappear because I only 'saw' it once in my head, I rehearse the first items at each input";

"I could visualise the first few items but difficult to visualise the others, I tried to map them out by forming a line in the grid and mapping my way around, it may be easier to just memorise them verbally";

"It isn't very hard, I make a path in my head in relation to the starting square and I picture the starting square and the square at which the path ends, I always relied on creating a picture which has a path or a shape in it instead of the whole matrix, I sometimes got confused because I was thinking of the words instead of the picture so there was some 'interacting' between listening and imaging, the beginning of the shape was easier to remember and if the shape was something familiar it makes it easier to recall".

<u>Condition 2</u>

-"It (the task) is demanding. If you lower concentration you get confused. If you lose the first move from the starting square you are lost. I tried both rehearsing letters (L,R,U,D) and using imagery in the form of routes on a map, the starting square is like a town centre and then move around it";

-"It is easy you just need to concentrate to be able to hold it in your memory. I move my eyes and body as the path moves. I don't take in the last few moves because I was trying to maintain the first ones. I tried to remember it as a list of words but it is too difficult so I tried to see them in my head as shapes broken into forms. So there was only the path and no squares. The path is in the form of lines or shapes like question marks";

-"Quite difficult. Hard to remember the beginning of the picture, relied on imagery, white lines in black boxes or a black background, no clear image of the grid, I tried rote memory once but wasn't helpful, much easier by imaging and closing my eyes, it is easier to image in the dark or even just stare at a black wall";

-"Difficult towards the end of each trial, easier to remember the first few items, relied on forming a picture, it doesn't work by just remembering words. So there was a line in my head going from the starting point, no whole matrix. I was mostly staring at the table with eyes open";

-"Quite difficult. I don't think I got any one completely right, mainly relied on the picture (imagery), it was in different forms like a hammer-head shark, a spiral shape, or just visualising stairs in a couple of them, no complete picture of the matrix, easier to remember the first ones and it becomes confusing at the end. No verbal memory at all. My eyes were open and it will not help to close them";

-"It gets harder as the trials progress because different shapes confused me, not too difficult or too easy, mainly relied on imagery, lines or snake-like shapes, tried verbal memory once but that confused me, a picture of the grid with a line in it, the best strategy is using imagery, no difference between the first and the last items";

-"Very difficult, I wasn't concentrating enough, easy to get distracted so I can't register what the guy is saying and that breaks the pattern, then you just don't know where you are, I was following a visual thing: units of lines joined up in the grid but the grid isn't always there, easier to keep my eyes open, tried verbal memory but doesn't work at all, first part of the line is much easier and in couple of them it was the other way around";

-"Quite difficult, if the matrix was there like in the first practice trial it would have been much easier, easier to remember the first few moves, tried memorising words but it didn't work because the words are confusingly similar (left, up, left etc.), so mainly relied on picturing the shape like a question mark, I just saw, in my mind's eye, a line in relation to the matrix but no squares, I stared at the table because there is where the matrix was, easier to fix my eyes and watch the line as if it was being drawn, I kept rehearsing the beginning of the line during input".

Condition 3

-"The task isn't too easy or too difficult. Some tests are easier than others. Tried to see it as a line, drawing a line around the thing. Harder to recall the last items. Relied mainly on creating a line (image). During recall I was staring at the blank screen trying to picture the 'box'";

-"The task isn't that hard. Trying to form images and then convert them into words at recall which made the task harder. Most of the images wheeled around the starting point in the form of a snail. I was trying to mentally form a line or a shape and then re-establish the matrix around it and that is kind of hard. Easier to recall the beginning of the line because it is near the starting square whereas the end goes off toward the periphery of the matrix and becomes not connected to the original square. Mainly used imagery. I tried verbal memory during practice trials but it didn't work. Tried to forget the previous images to avoid confusion. Tried to predict where the path goes and it helped if I was right. I tried to imprint the picture on the screen in my head, it is like when you stare at the sun and then move there is still something in the back of your eyes";

-"The task is of a medium difficulty. If I lose one move I lose my confidence. I was seeing pictures in my head. The picture is of a shape not the whole matrix. The first part of the shape is easier because I kept looking at it as it builds up. I was staring at the blank screen during recall since it focuses my concentration. It is best to stare at something. If you don't lose the pattern while you are creating it you are OK. I didn't just memorise words, I 'looked' at pictures of squares in groups in relation to one another as it builds up";

-"The task is reasonably easy. I was seeing patterns in my head not within the whole matrix. During presentation I was staring at the screen trying to imprint the line in my head and put it 'upstairs' so I could remember it. During recall I was transferring the image into words and trying to recall immediately because if I waited the picture will start fading. I was picturing the way it moved around the starting square before it goes to the sides of the matrix. So there was a pattern in my head within the relevant sections of the grid. It was easier to recall the beginning of the pattern. I didn't just rehearse words";

-"The task is of a medium difficulty. I tend to forget the last couple of crosses because I was verbalising the first ones. Easier to recall the beginning of the line because I concentrated more on it. I used verbal memory but there was an image to refer to when I got stuck. I was sometimes imagining the pattern as stairs or a question mark, sometimes I was able to guess where it was going. I didn't try to count how many squares. There was imaging backed by rehearsing words";

-"Not too hard, I was remembering sequences of L, R, U, Ds backed up by a picture. So I tried to see where the pattern went and tried to remember a sequence of letters (L, D, L, U, etc.) and fit them in with the picture. So you fall back on the picture in case you forget the sequence of letters. The picture was like a line that went through the squares. I black out the relevant squares. At recall I was staring at the blank screen trying to visualise the grid since there is where it was. Easier to remember the first 4 or 5 squares as a pattern and the last 3 squares are the most difficult";

-"It was all right to begin with but as it went on I forgot where the end point was. Visualised the path but not necessarily the blocks, you just get the general trace of the line. At the begining, I tried using verbal memory in the form of series of L, U, R, etc. but then I changed to imaging. Using words may be easier. I was staring at the blank screen and there was a visual thing in my head. The first trial is easy because you only saw one path but as trials progress you get confused. The task wasn't too difficult and I wasn't sure that I always recalled 8 squares";

-"The task is difficult, during recall I was trying to picture it in my mind and I found that by the 6th or 7th square I was guessing where it ended. I was trying to get the picture and form images but also to memorise (verbal recoding) series of up, left, etc... The image was a path and then I try to imagine it within the grid. Harder to recall the end of the path because for the first ones, I had time to repeat them in my mind as words like up, left, etc. At recall, I was staring at the blank screen trying to imagine the grid again. I 'saw' the crosses and the shape not the whole matrix. I wasn't always sure how many items I recalled"

<u>**Condition 4**</u>

-"It (the task) is OK, you have to concentrate hard because if you lose where the path went you lose it, It makes it easier when you remember where it ended, I was using an image not words, visualising a shape involving only the relevant squares, Beginning of the shape is easier since it is near the starting point and when it starts moving away it gets harder because you have no idea where it will finish. Handing me the recall sheet is a bit distracting since at that time I was struggling to keep the picture in my mind and it would be nicer if it was already there";

-"It is of medium difficulty and makes you think, the first 2 trials were really easy and some trials are difficult because I get them mixed up with the previous ones, I remembered the direction of where it goes, it was a line or a shape of groups of squares, so just remembered the way it moved around and then drew what I saw, didn't just remember words. Beginning of the shape is easier since it is easier to remember where it heads off but as it gets toward the end you don't remember it so well";

-"The task is easy in the beginning but as trials progress it gets harder because you have various images or shapes in your mind that confuse you, just followed the direction and then drew it whilst checking that I got 8, so I traced the path around like a line, no words, just a line circling around the starting point, easier to remember the beginning because of the starting x, so I kept tracing the x in relation to the stating point";

-"It is of medium difficulty, it wasn't easy because I had to concentrate but it was not too difficult because I think I didn't make mistakes, I tried to draw a picture of the path in my mind as a Q. mark or a shape that I trace and I remembered the deviations from the Q. mark. The crucial element is drawing a line in my head, if I didn't do that it would be difficult, the line tends to mostly go around the starting point which made it easier. I didn't use words, it would be impossible to remember the whole pattern as words. So there was a mental shape within a vague picture of the matrix, I was only concentrating on the shape because if I tried to remember it within the whole matrix it would be more difficult and it would create doubt, It is easier to remember the beginning and then the middle of the line, the end is more difficult because I only 'saw' the final x for a second, first trials are easier because it gets more difficult to maintain my concentration as the trials progress";

-"Medium difficulty because you sometimes lose the way, I followed the x as it moved and kept drawing it in my head, It is an image like a question mark, the relevant squares get superimposed, they stand out like a shape, it helps if it is a familiar shape, I may used a word for the first move like (up) but then I just trace the shape that I then stick in my head as an image, once the image appears in my head I just forget the word, the beginning of the shape is easier to remember because by the end, you just wonder how many squares it went through, the more trials the more difficult it gets because you get confused by different shapes";

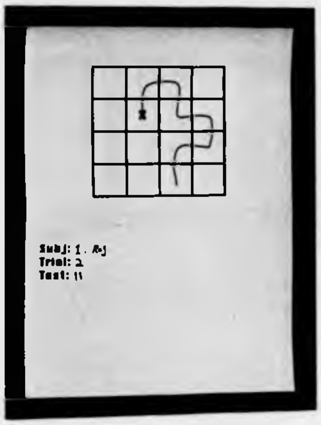
-"Some tests are quite easy & some are quite complex, the ones that formed a circular shape are more difficult, the last trials are harder because I peaked my concentration in the first trials. It was almost like a deferred image in memory, I made out the line, the last x is the crucial one, no words just an image or a line within parts of the matrix, the crucial thing is to concentrate to form the line, the beginning of the shape is easier since it is the first thing that happens and you 'see' it in my mind more, it is like the alphabetic you know the first letters better, I confused my self by wondering and predicting where it will go rather than relaxing and watching";

-"Not too bad, I formed a shape of squares and remembered the deviations from it, tried to keep the relevant squares in my head as a pattern of squares that stands out, it is important to maintain an image of the relevant squares and their order, so I thought of them as actual squares in a certain order rather than just a line. No words, their use didn't occur to me. The beginning of the shape is by far easier because it is similar in most trials whilst the end tends to vary, the starting square is like an anchor. The last trials are harder as the shapes get harder to keep track of. Handing me the recall sheet is a bit distracting, the interval between display and drawing is important and if it was longer it would cause problems";

-"It is easy to medium, I remembered the sequence of steps visually as a shape in my head, it wasn't just a continuous line but it was broken down to where it moved from and where it stopped at. No verbal memory, I tried it for the first 3 moves in the first trial but didn't work, so I only used the visual strategy. Beginning of the shape is easier because I keep remembering it whilst it is still carrying on. Handing the paper isn't distracting, As trials progress it gets easier because you work out a strategy. Some tests are harder than others, the further they go from the starting point the harder they get, If 3 or 4 squares are close to each other you could just categorise them as one step"

Appendix 5.1

Experiment IV. Illustrations of the material & experimental set-up

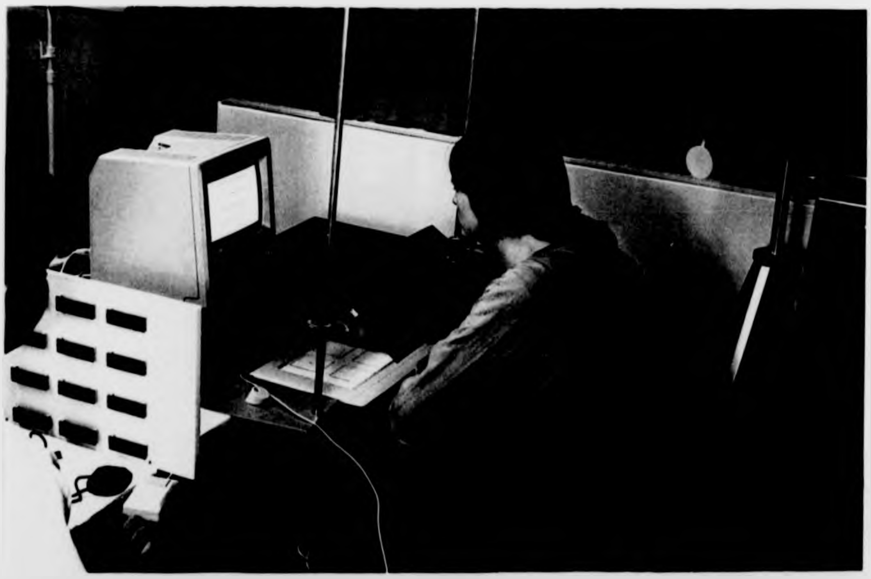


(1)

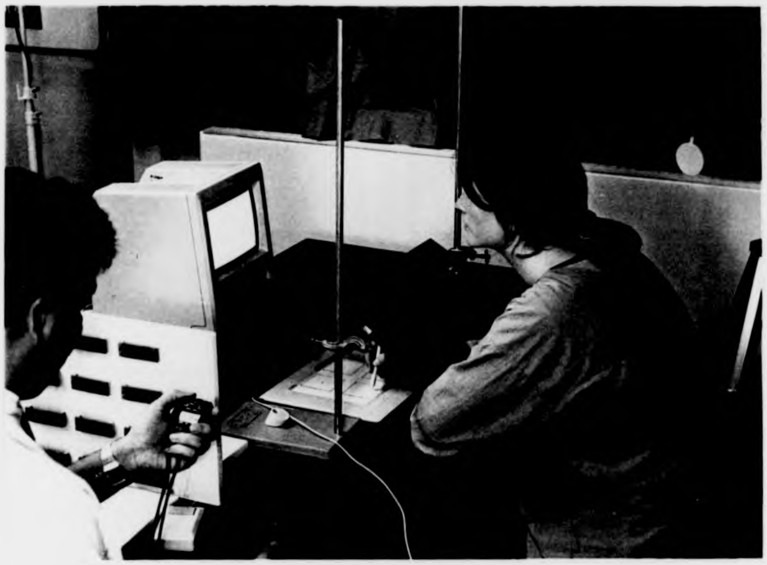
(2)

1) An example of a 'recall sheet' with a line drawn on it.

2) The new tapping apparatus: a Wacom digitiser consisting of a Tablet & a cordless Stylus. A paper containing 4 tapping targets is inserted underneath the transparent overlay.



Experiment IV: The subject visually encoding the task by watching a set of 8 displays of the matrix on a computer screen.



Experiment IV. The subject tapping in time to the signal during the 30-seconds maintenance interval whilst the experimenter is timing the interval.

Experiment IV. The subject visually decoding the task after the maintenance interval.

Appendix 5.2.

The additional 9 sequences constructed for Experiment IV:

TEST 9:

STARTING SQUARE
UP
RIGHT
DOWN
DOWN
LEFT
LEFT
DOWN

TEST 10:

STARTING SQUARE
LEFT
DOWN
RIGHT
RIGHT
UP
RIGHT
DOWN

TEST 11:

STARTING SQUARE
DOWN
RIGHT
UP
RIGHT
DOWN
DOWN
LEFT

TEST 12:

STARTING SQUARE
LEFT
DOWN
RIGHT
DOWN
RIGHT
RIGHT
UP

TEST 13:

STARTING SQUARE
RIGHT
DOWN
LEFT
DOWN
RIGHT
RIGHT
UP

TEST 14:

STARTING SQUARE
UP
RIGHT
DOWN
DOWN
RIGHT
DOWN
LEFT

TEST 15:

STARTING SQUARE
LEFT
DOWN
RIGHT
RIGHT
DOWN
RIGHT
UP

TEST 16:

STARTING SQUARE
UP
RIGHT
DOWN
RIGHT
DOWN
LEFT
DOWN

TEST 17

STARTING SQUARE
RIGHT
DOWN
RIGHT
DOWN
LEFT
LEFT
UP

Appendix 5.3.

The script of each of the 4 HC buttons to emit a sound and record the time in a file:

```
on mouseUp
  play "metal"
  global filename
  if filename <> "" then  write the short name of me & the ticks && empty to file
          filename
end mouseUp
```

The script of the HC stack to create a data file for each subject:

```
on OpenStack
  global filename
  ask file "Please enter subject number here"
  if it = "Cancel" then put empty into filename
  put it into filename
  if filename <> "" then open file filename
end OpenStack

on CloseStack
  global filename
  if filename <> ""then  close file filename
end CloseStack
```

The HC script of the card used to emit the 'board' sound when the subject missed a tapping target and to record the time of the *miss*.:

```
on mouseUp
  play "board"
  global filename
  if filename <> "" then  write the short name of me & the ticks && empty to file
  filename
end mouseUp
```

<u>The HC script of the card used in order to leave a space in the data file if the 'return' key is pressed:</u>

```
on returnKey
  global filename
  if filename <> "" then  write return & return to file filename
end returnKey
```

<u>The HC script used for emitting & repeating the auditory signal at the regular interval of 1 second:</u>

```
on mouseUp
  repeat 600
    wait 60 ticks
    beep
  end repeat
end mouseUp
```

<u>The HC script for obtaining the random auditory signals:</u>

```
on mouseUp
  repeat 600
    global randomList
    wait 29 ticks + random(61)
    beep
  end repeat
end mouseUp
```

Appendix 5.4

Instructions for Experiment IV

1) The introduction of the matrix task:

After the initial introduction of the experiment and the matrix task to the subject, show a 4x4 matrix with the starting square marked. Then say:
You will see a set of 8 displays of the matrix on the computer screen that show a path within the squares of the matrix. The path will always begin from the same starting square (give an example).

After you have seen all of the 8 displays, you will be presented with a recall sheet that has a 4x4 matrix drawn on it. Your task will be to draw a line on the matrix representing your mental image of the path.

You have to attempt to remember the path by forming a mental image of the path within the matrix. You could then use that image to help you recall the path. There is no limit on response time. Let us do a practice trial:

2) The no interference condition:

..........Now recall of the path will be after an interval of 30 seconds which starts immediately after the last display of the matrix had been presented on the computer screen.
During this interval, you are requested to do nothing other than to try to remember the path through the matrix.
After the 30 seconds interval, a recall sheet will be handed to you and your task is to draw a line on the matrix representing your mental image of the path.
Let us start off with a practice trial.

3) Simple tapping condition:

...........Now recall of the path will be after an interval of 30 seconds which starts immediately after the last display of the matrix had been presented on the computer screen.
During this interval, you are requested to keep remembering the path through the matrix. Also, during this interval, I would like to tap, using the stylus, on this square. You should tap on this square every time you hear the auditory signal which is at the rate of one beep per second. You should tap in time with the auditory signal. You should stop tapping when the auditory signal stops at the end of the 30 seconds interval.
After this interval, a recall sheet will be handed to you and your task is to draw a line on the matrix representing your mental image of the path.
Demonstrate this tapping task to the subject and give some training. Then: let us start off with a practice trial.

4) Regular spatial tapping:

...........Now recall of path will be after an interval of 30 seconds which starts immediately after the last display of the matrix had been presented on the computer screen.
During this interval, you are requested to keep remembering the path through the matrix. Also, during this interval I would like you to tap, using the stylus, round these 4 squares in turn in a clockwise direction.

You should tap each square in its turn every time you hear the auditory signal which will be at the rate of 1 beep per second. You should tap in time with the auditory signal and try not to miss any square. You should stop tapping when the auditory signal stops at the end of the 30 seconds interval.
After this interval, a recall sheet will be handed to you and your task is to draw a line on the matrix representing your mental image of the path.
Demonstrate this tapping task and give some training. Then: let us start off with a practice trial.

5) Random spatial tapping:

...........Now recall of the path will be after an interval of 30 seconds which starts immediately after the last display of the matrix had been presented on the computer screen.
During this interval, you are requested to keep remembering the path through the matrix. Also, during this interval, I would like you to tap, using the stylus, round these 4 squares in turn in a clockwise direction.

You should tap each square in its turn every time you hear the auditory signal which will be at variable intervals between half and 1.5 seconds. You should tap in time with the auditory signal and try not to miss any square.
You should stop tapping when the auditory signal stops at the end of the 30 seconds interval. After this interval, a recall sheet will be handed to you and your task is to draw a line on the matrix representing your mental image of the path.
Demonstrate this tapping task to the subject and give some training. Then: let us start off with a practice trial.

Appendix 5.5.

Subjects' reports in Experiment IV

Subject 1: "Hardest condition was the irregular tapping because you had to completely forget about the matrix, thinking about when the beeps are coming disrupts the picture of the path; The control condition was the easiest because during the interval you just remember the picture, The regular spatial tapping is like simple tapping because you can just tap and keep thinking about the matrix, so there is more of a mechanical element; The image was a pattern of blocks and the pattern was harder when it went up toward the angels in a snake-like shape and it was easier if it made a circular shape, the end of the line is harder to remember because I think of the first six moves and then work out where it ended; During the empty 30 seconds' interval I just remembered it in my mind as a picture of a line of blocks, it is like a snap-shot, With other conditions, especially the random condition, I used the same image but I tended to forget it for couple of seconds and then I go back to it to make sure it is still there".

Subject 2: "Hardest condition was tapping at different times because it demanded concentration, it requires concentration on both the locations of the targets (where) and the timing of the beeps (when); I didn't need to concentrate on the image except in a couple of them where I needed to go over the image in my mind but in the rest I just saw the path then thought about it for couple of seconds and then blanked it out in the back of my mind and concentrated on the tapping. I just put the image in the back of my mind and I could do any thing else, even random tapping, except something that involves similar shapes which will confuse me. So I just stamped it in my memory whilst tapping and then I could bring it back at recall (incidentally, the tapping data showed that this subject in particular didn't comply with the random tapping instructions). Easiest was both the control and simple tapping conditions. During the empty interval, I went over the shape for the first five seconds and then deliberately thought about something else because if I think about it too much I will get confused. In the regular condition, it was a bit difficult to remember the pads but it wasn't as hard as the random. The image was a shape of the path, there was a general idea of where the shape went within the matrix, I remember the first moves and then work out the rest, so the beginning of the shape is a bit easier. There were a few basic patterns of whether it went around or toward the edges; No words, hard to think of it as directions so just an image".

Subject 3: "Hardest condition was the different times condition because you have to listen and wait for the beeps whilst in other conditions you get into the rhythm and get going. I had to concentrate on the beeps and the image and they competed for my attention, Random tapping really caused some problems with the image. The easiest condition was the control, I was going over it more precisely, I was going over it as up, down, across etc. and also looking at it in more details in my head. The regular tapping was less harder than the random but in both if I missed a target it made me focus on the tapping more than the shape. The matrix task wasn't that hard except when it was combined with random tapping. The end of the shape is the hardest to recall; occasionally used words but only in the control condition, in the other conditions I only went over it as an image, I was thinking of the path as a picture whilst tapping rather than thinking of a verbal description; the image was a shape rather than a picture of the matrix".

Subject 4: "Hardest condition was the various beeps condition because you have to remember the locations of the 4 squares (the where) and also concentrate on the beeps (the when); it was easy to remember the path, the image was like blocks I went through them and shaded them in my mind, I remembered each 3 moves as one step or line that is in a different colour from the other step, the end of the image is harder because you forget which direction it ended at, so in general I just remembered the squares it went through as an image of shaded squares and never used words, some paths were more predictable so they were easier than others. Easiest condition was the control, I was doing the same thing but concentrating more on the image and its end. Tapping the 4 squares was hard especially starting off and remembering where to go, if I missed a target I get confused".

Subject 5: "Hardest was the random tapping since it required concentration and it was very difficult to tap and also remember the path, when the interval between beeps is long you get more time to think about the path but suddenly you get a burst of quick beeps and that turns you off, If my attention goes to the path I tend to miss the tapping targets and it becomes hard to get back into the sequence, this random tapping didn't give a room to refresh the picture and if I did I make tapping mistakes, in this condition I wasn't sure of the path I was remembering I confused the path with the one before, I was remembering the first move as a word and the rest of the moves as a pattern like a zigzag, a calliper, or a loop with a tail which goes round the squares, I got all the patterns mixed up, sometimes it was easier not to remember the line but just the parts of the grid that were blacked out by the path, I could not just put the image in the back of my head and leave it there whilst tapping unless I could latch it onto something familiar like a letter. The regular tapping was routine and you know where you are going so you could try and 'see' the picture whilst tapping. The easiest condition was the do nothing I was rehearsing the picture, I first try to bring back the visual picture using the start word and then I just go over the picture in my head, so during the empty interval I had the chance to correct mistakes because I knew I needed 8 squares, I was counting the squares in my head as I went through the path, sometimes I visualised the path on the blank screen and that helped, I could keep a visual image for only a very short time unless I can latch it on something familiar. Only with the random condition that there was no room for rehearsing the image. Some patterns are easier than others, Easier to remember the beginning of the shape unless the end was very predictable, you don't have to remember all the movements of the path but just the first movement to get you started and then the rest as an overall picture. The matrix task on its own was simple because the matrix is small and the path cannot go diagonally."

Subject 6: "Hardest condition was the random tapping because you have to concentrate and listen out for the beeps and that keeps your mind drifting from the image and the image shifts to the back of your mind and although I can remember it, it isn't as good as the others. With this condition, I had pictures more than words because I can't keep words in my mind whilst randomly tapping. The picture was there in the back of my mind and I was concentrating more on the beeps. The picture was a line of the path not a whole picture of the matrix. During presentation I tried to take in as much details of the path as I can and then I just kept it there and switched off to concentrate on the random tapping. The regular tapping was less distracting than the random because it is predictable so you don't have to listen out for the beeps so much. Easiest were the control and simple tapping. Simple tapping may be easier than the control because when I had nothing I felt I was forgetting the image because my mind was wondering around, there was nothing to concentrate your mind. Because simple tapping was even and easy I was able to pay attention to the image in my mind. For most of the trials, I tended to remember the path as words for the first 3 moves and the rest of the moves as a picture of a shape. If the shape went all around the place it becomes harder. Beginning of the shape is easier because when it goes toward the edge you get loads of information to remember".

Subject 7: "Hardest was when it involved tapping round whether it is the steady beep or the out of time, it is just hitting the 4 squares because if I missed one it would put me off. The irregular beep required a lot of concentration because it is a mixture of short and long intervals but the regular is very repetitive and you could follow a beep of your own. Random tapping may be more difficult since you have to think about both the spacing and the timing and that causes a problem with memorising the path because there is too much in your memory. Easiest was the do nothing because you just sit back and think about how the path went, I was following the path in my imagination as a picture of the matrix on the computer screen with the squares coloured in sort of a line which I followed over and over again. Random and regular tapping definitely stopped me from thinking about it but simple tapping didn't because I didn't have to concentrate. During tapping round I only thought about the path once. If the path makes a regular pattern like a zigzag it becomes easier. Beginning of the shape is much easier to recall because I pay more attention to it to initially start me off and then work out the end. The more the trials the more I get confused because I remember lots of different paths"

Subject 8: "The random was the hardest because you can't get into a rhythm, you have to concentrate on both the spacing (where) and the timing (when) and that made it harder to keep the image in my mind. Simple tapping was the easiest because it made me concentrate on the path but in the control condition my mind was wondering around that I could not keep the image. Regular tapping was quite difficult because you still do the squares but not as difficult as the random since you know when it is going to beep so I tapped and rehearsed the image at the same time, I was 'seeing' the line on the blank screen. The image was like a square or a box with a tail, not a full picture of the matrix, just the squares blacked out like a shape. If a shape curves around itself, it is easier from the one that goes off toward the edges, beginning of the shape is easier because I try to remember the first 2-3 squares and the end becomes harder because sometimes I could not work out how it ends. During the interval, it was a shape in my mind and when I drew it I was deciding where that shape was within the grid."

Subject 9: "Easiest was the control, I just kept retracing the steps of the cross until I drew it, I tried to visualise it going around the squares and then I do some chunking of the relevant squares so the image was of these shaded squares as a line not a whole matrix. Simple tapping wasn't that hard and regular tapping was slightly worse. The Hardest was random tapping because you concentrate on two things where to tap and when to tap. I don't think tapping affected the matrix task, I tended to put the image aside during tapping and then bring it back which was hard but I found I could do it. Beginning of the shape is much easier because I tended to chunk the first 4 moves as a familiar shape and then work out the end, If the path made a familiar shape like a rectangle it makes it easier, if the matrix was 5x5 I reckon it would be more difficult because now it is small and more predictable."

Subject 10: "Hardest was the control because I was going over it again and again and then becoming unsure of it , I confused my self by going over it so many times. Random was quiet difficult because you can't get into a rhythm so you have to anticipate the beeps but it didn't cause more problems in recalling the path. The path was up there during tapping and I just went back to it at recall, it doesn't fade and if I had problem it is because I initially saw it wrong, I could hold the image up there and do any thing and then go back to it. Regular tapping was OK, it is just hitting the squares, missing a target causes confusion, remembering the path is easier than tapping round. Simple tapping was the easiest. The image was of a pattern, every time the path went through a square it changes colour in my mind and I blacked it out so there is a pattern at the end. After tapping, when I go back to the image I tended to confuse it with the previous shapes but once I start drawing it is OK. The beginning of the shape is easier because it always make a familiar shape like a square or a spiral. I never used words, it was always a visual pattern like a snake or a square with a tail etc."

Subject 11: "Hardest was the random tapping, it takes too much concentration, not like the regular in which you keep going out of the habit, in one trial my mind went blank at recall and I drew a previous path, this didn't happen with the regular since you just get into the sequence and get going. The image was the actual line that I was going to draw, it was a line within the whole matrix, random tapping made me unsure of it since it distracted me from *scanning* the image. Control was the easiest, there was the same line but I had the chance to just fully concentrate on it. I mainly relied on the image but a few times when the path was irregular and hard I used words because it isn't easy to see it as a line. I occasionally used words only in the two easiest conditions. Beginning of the line is easier because every time I scan or think of the line, I redraw the beginning in my head. I didn't just put the image aside whilst tapping, During simple and regular tapping, I was concentrating on two things at once which are the image and the tapping, that is why I had problems with random tapping because I had to leave the image and concentrate on the tapping and that made it hard to get the image back."

Subject 12: "Hardest was the random since I had to concentrate hard on the tapping which made recalling the image worse, The easiest condition was simple tapping because I didn't need to think about the tapping but it gave me some thing to do and thus helped me to concentrate on the image, in the control condition I had nothing to do so my mind just wondered about, I tried to make a very accurate picture of the path by thinking too much about it and that confused me but in the other conditions I had only a rough image or idea of where it went. I tried to form an image of the movements of the cross, the image was a shape like a letter, the first movement of the X is very important to remember. Every now and then during tapping I went back to check the image and that is when I made tapping errors, this rehearsing was mainly disrupted by random tapping. Regular tapping wasn't that hard but you still have to think of the movement of your hand as well as the movement in your head. I prioritise the matrix task over the tapping task despite the instructions not to, may be because it was introduced first and you also get to see what you have done (i.e. the drawing) whilst with tapping you do not"

Subject 13: "Random was hardest because you can't get into a rhythm so you can't concentrate on the memory of the matrix. Control was the easiest and there was more of an aural thing than a visual thing but I was still tracing something like a line with my finger, in the other conditions I was tracing it in my head as a black line and only the random tapping caused a problem with this tracing because I was waiting for the beep. During simple tapping there was the chanting in my head (up, left etc.) but I suppose I can still see the line. The image was of a line with no matrix or a cross only what I was going to draw, beginning of the line is easier to recall because I tend to forget the last movements, if the path goes all the way across the matrix it becomes harder. During regular tapping I could 'see' the line at the same time but if I miss a target I panic and get confused with the image. It is difficult to tell exactly what was in my memory because sometimes I am not aware of it, I know I remembered something but not exactly how".

Subject 14: "Random was the hardest because I was trying to keep in my mind's eye a picture of the matrix pattern whilst also trying to concentrate on the random beeps. Control was next to random tapping in terms of difficulty because I concentrated too much on the image and tried to read too much into it than there actually was, Simple tapping was the easiest because it gave me some thing easy to do and there was a room for keeping and rehearsing the image, with the control I needed something to fiddle with in my hand or something to help. The regular wasn't that bad because you can get into a rhythm but with the random you have to concentrate on both the targets (the where) and the timing of the beep (the when). In my mind's eye there was a mental picture, I tried to concentrate on the path at input and see if it is in a square or a rectangular shape, it was a full picture of the matrix with the actual boxes blacked out, so I concentrated not on the X but on the pattern of squares and what shape they will make, in the tapping conditions I tried to keep the first six movements as a shape and then guess the others but in the control I tried to get all of the 8 movements as a shape, during the interval I see the image on the empty VDU screen because there is where it was. During the random condition I get the image during input and then just keep it there in my head and concentrate fully on tapping then I go back to it and scan it and it is still there and if it fades it is only the last two movements that fade. During the two spatial tapping conditions I didn't keep the image in front of me because I had to visualise the 4 tapping targets on the hard-board screen rather than keep the picture, If I did them both at presentation that would jeopardise the picture and I would lose the path but now once the path goes off the screen I can keep it up there and then concentrate on the tapping."

Subject 15: "Random tapping was the hardest because concentration causes a problem with keeping the image, the easiest was the control followed by simple tapping. Regular tapping was easier than random because you don't have to think about the beep. I relied on creating a mental picture of shaded blocks, I initially tried using words but it didn't work so just a picture. During the empty interval, I just went through this line of blocks. During tapping round I kept this line and didn't just put it aside in my mind and if I missed a target I try to get back into the swing of the beeps and that disrupts the vision in my mind. Beginning of the line is easier because it is fresh in my mind and I pay more attention to where it started."

Subject 16: "Random and control were the hardest conditions, recalling the path was better with the other two tapping conditions, in the do nothing condition it was harder to remember the track because I think too much about it and that makes me confused, I tried to think about exactly where it has gone and that was more difficult than just thinking of it as a shape, so thinking of which individual square it crossed each time was more difficult than just remembering it as a line or a pattern. In the tapping conditions, I didn't think too much about the path, I just knew I remember a shape that I plot on the blank screen, I only forget it if I think too much about it otherwise it stays there as a static shape, so the crucial element to remember the path is not to think too much about it once encoded, in general when I try to remember something I forget it quickly if I think too much about it. Random was hard because you have to keep up with the beeps but that didn't distract my memory for the path, simple tapping was the easiest because it gave me something easy to do so I do not think too much about the path. The image was of a shape which was easier if it makes a square than if it goes backwards and forwards before it finishes, if it makes a distinctive shape it becomes easier, sometimes you get confused with the previous shapes, never used words, I was surprised that it was hard to remember the shape when there was no tapping"

TITLE	MOVEMENT INTERFERENCE IN VISUO - SPATIAL WORKING MEMORY
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